A flexible business model for the ETP Wijster

Final report

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Summary

The traditional energy industry is transitioning from a centralised fossil fuel based industry to a decentralised renewable energy industry for several reasons including climate change, policy, and changing customer needs. Furthermore, renewable sources, such as wind and solar, are intermittent and unpredictable. This has implications for the business models of energy producers, such as increased mismatch between demand and supply, increased price volatility, shift in drivers of value creation. Due to the low marginal cost of production and the intermittent nature of renewables, the price volatility on the electricity markets, in particular the imbalance market, are expected to increase. However, there is potential for market parties operating in the electricity sector to profit from this development by providing flexibility to balance electricity supply and demand. Therefore, new business models are needed that can harness and exploit flexibility in a viable manner. In these business models, flexibility becomes the key driver of value creation.

At the same time, district heating networks are gaining attention as one of the pathways to energy efficiency. The district heating sector is looking for new business models to develop district heating networks in industrial settings and residential areas that are economically attractive. Furthermore, heat is comparatively easier and cheaper to store than electricity. Therefore, heat networks have the potential to store excess electricity from renewable sources and supply electricity when there is shortage. Hence, integrating heat and electricity grids in an intelligent manner can provide the much-needed source of flexibility.

Against this backdrop the Energy Transition Park (ETP) in Wijster wants to realize a flexible, multi-commodity, intelligent, and economically attractive industrial park for energy intensive industries. In this study we have developed and validated a flexible, multi-commodity business model for the ETP Wijster that will allow all the stakeholders at the ETP to harness the flexibility embedded in the industrial processes and successfully commercialize it. The waste incineration plant of Attero now produces electricity and heat for external delivery in fixed amounts. In the flexible business model, heat and electricity are produced in varying amounts, depending on the electricity prices. When the electricity prices are high, electricity production is ramped-up and at the same time, the flexible consumers reduce their consumption of heat and vice versa. Hence enabling them to exploit the arbitrage opportunities that exist on the commodity markets.

This leads to our research question:
How can Attero and its partner firms at the energy transition park Wijster develop and exploit a viable flexible multi-commodity energy system?

To answer the research question we have designed and validated a business model that enables Attero and the industries at ETP Wijster to successfully harness the flexibility and exploit it on three different commodity markets, namely the day-ahead market, the intraday market, and the imbalance market. Different heat consumers with different sources of flexibility can be connected to the heat network. In this case-study, we have looked at industrial customers that can shift their heat consumption in time and in quantity, a district heating network connected to a heat buffer and a power-to-gas facility using low-temperature heat for power production. All participating firms can trade their flexibility on an internal trade platform by placing bids for a deviation in the contracted or planned heat consumption at a certain price.

We validated the technical architecture and the financial viability of the business model. We validated the technical architecture through expert opinion and the financial viability by simulating trading strategies using a techno-economic model based on historical prices from the three commodity markets. The techno-economic model calculates the optimum revenue that can be generated within the given flexibility constraints. The model first optimizes the production of heat and electricity for the APX day-ahead market. The model next analyses the price development on the intraday and imbalance markets on a 15 minute basis, and modifies the original planned steam production pattern in order to take advantage of high electricity prices.

Even though there is not enough flexibility available at ETP Wijster to successfully exploit flexibility , the designed business model can become financially viable if the amount of flexibility increases in terms of quantity. Additionally, higher price volatility also positively influences viability of the business model. We used the 2015 commodity prices for simulating the trading strategy of Attero. The price volatility for the year 2015 was t at a historic low for the day ahead market. Nevertheless, experts expect that volatility will increase as the share of renewables increase.

Nevertheless, the firms at ETP Wijster can still implement the designed model profitably with the available amount of flexibility if the there is no additional investment required (for more details see 8.1). Furthermore, ETP Wijster should start acquiring the necessary technological, trading, and operations capabilities to implement the business model. Doing so will allow ETP Wijster to offer new value propositions to industries to relocate to ETP Wijster such as lower energy costs. Finally, they should start simple by trading on the day ahead market first and gradually increase the complexity by integrating the intraday market and the imbalance market. This helps them to mature and will help the transition process of their business model.

1. Introduction to the Flexiheat project

The energy landscape is rapidly changing due several reasons such as the development of new technologies, penetration of intermittent renewable energy sources, change in customer needs, policy, etc. Renewables represented approximately 58.5% of the net additions to the worlds power capacity in 2014 (Sawin, 2015). Hence, we are becoming increasingly dependent on intermittent energy sources such as wind and solar. The intermittency poses a significant threat to the stability of the grid and for the security of supply as the imbalance between electricity supply and demand will occur more often. Therefore, there will be a need for flexible sources of energy that can be engaged when there is a surplus or a deficit in the supply of energy. Furthermore, these renewable generation technologies have a very low operation costs compared to fossil fuel based generation technologies. This means that the price of energy will be low when there is abundance of solar and wind energy, and the prices increase when other forms of energy generation units have to be engaged, such as gas fired power plants etc. Hence, the energy markets will increasingly become volatile. Furthermore, the ability to store energy and to modify consumer demand will also play a crucial role in the energy industry that is dominated by intermittent sources of energy. Consequently, flexible production and consumption of energy will be the new source of value creation. However, the business models of companies in the energy industry are not geared towards harnessing and exploiting flexibility. They are geared towards producing energy centrally, reliably, and at a low-cost. The above-mentioned changes in the energy landscape offers potential for the stakeholders in the energy sector to develop new business models that will enable them to harness and exploit flexibility in a viable manner.

At the same time, district heating networks are gaining attention as a pathway to energy efficiency. However, the financial feasibility of district heating networks is under pressure. Heat prices need to compete with natural gas prices, the dominant fuel for heat production in the Netherlands. The district heating sector is looking for new business models to develop district heating networks in industrial settings and residential areas that are economically attractive. However, heat is an energy commodity that is much more suitable for storage than electricity. Therefore, heat grids have the potential to store excess power from renewable sources and supply power when there is a shortage of power. Hence, integrating heat and electricity networks in an intelligent manner can be an important source of flexibility.

Against this backdrop the Energy Transition Park (ETP) in Wijster wants to realize a flexible, multi-commodity, intelligent, and economically attractive industrial park for energy intensive industries. They want to do this by fostering inter-firm exchange of flexibility, and different forms of energy. The waste incineration facility of Attero, located at the ETP, offers different energy products including electricity, biogas, LNG, and heat of different qualities. It currently sells the produced electricity on the forward and day-ahead markets and retails steam to an industry located at the ETP Wijster. Supplying waste heat to third parties is an effective way to improve Attero's R1 status, a measure for the overall efficiency of the plant.

In this study, a flexible multi-commodity business model is developed in which the waste incineration plant is flexible in its heat and electricity output by responding to price changes on the electricity markets. In this '*multi-commodity energy business ecosystem*', the business conditions to locate at the ETP will improve by lowering energy costs. This creates a new value proposition through which new firms can be attracted to locate at ETP Wijster. This leads us to our main research question:

How can Attero and its partner firms at the energy transition park Wijster develop and exploit a viable flexible multi-commodity energy system?

In order to answer the above research question we benchmarked the energy business models of the greenhouse sector. The greenhouse sector has been successfully setting up and exploiting flexible energy business ecosystem for over a decade (Van der Veen, 2012; Velden & Smit, 2014; Wetzels, van Dril, & Daniëls, 2007). Together with a background study on the Dutch electricity market, we used this as an input to develop a flexible business model that is specific for the ETP Wijster. The business model harnesses Attero's flexibility, i.e. its ability to adapt the ratio of steam used for electricity production and for external heat delivery, and the flexibility of partner firms i.e. shift heat consumption in terms of quantity and in time. The business model then exploits this flexibility on several markets such as day ahead market, intraday market, and the imbalance market. In order to validate the business model we developed a techno-economic model to simulate trading strategies on several markets with historical market prices.

The report is organised in three parts. Part 1 presents an overview of the electricity commodity markets. Part 2 describes the energy business models of the Dutch greenhouse sector. Part 3 presents the business model for ETP Wijster. First, the business model concept is explained (Section 6), then is described how the designed business model was validated (section 7), and the validation results, and finally the business case is presented (section 8). Finally, section 0 presents the conclusions and recommendations for Attero.

The deliverables of the study are:

1. An analysis of the electricity markets
2. A benchmark of the greenhouse horticulture sector
3. A flexible business model concept
4. A technical-economic model to validate the business model

2. Method

2.1 Research design

The first step in the study is to conceptualize the problem. The initial thought was to design a business model to profit from high prices on the imbalance market by changing the ratio of steam used for external heat delivery and for electricity production. After further analysis of the research issue we have come up with a good understanding of the context and a clearly defined research question. We have learned that not only the imbalance market is interesting for trading flexible power, but also optimizing the trade on the APX day-ahead market and trade on the intraday market is worth studying. Figure 1 shows the different steps of the research.

We have identified similar business ecosystems to use in our analysis. We benchmarked the energy business models in the Dutch greenhouse sector. From this benchmark we distilled a set of lessons learnt and used them as an input to design four high level business model concepts for ETP Wijster. After discussing the concepts with Attero we chose one of the concepts and further developed the business model by describing the roles and responsibilities of the different stakeholders, mapping the technical characteristics of the business ecosystem and the information services that need to be developed.

We validated the business model first by expert interviews. A techno-economic model is developed to calculate the potential revenue. The model is programmed in VBA, Excel and it uses energy demand and consumption patterns and electricity prices to calculate the optimal production of heat and electricity given the day-ahead electricity price and the available flexibility, expressed in a quantity shift and a time shift of steam production. Further, the model analyses the price development on the intraday and imbalance market on a 15-minute basis, and modifies the original planned steam production pattern in order to take advantage of high electricity prices. The resulting energy production plan shows the optimum revenue generation that is possible within the given flexibility constraints.

We validated the business model financially with the construction of business cases, which do not only show potential revenue, but also profit (financial feasibility).

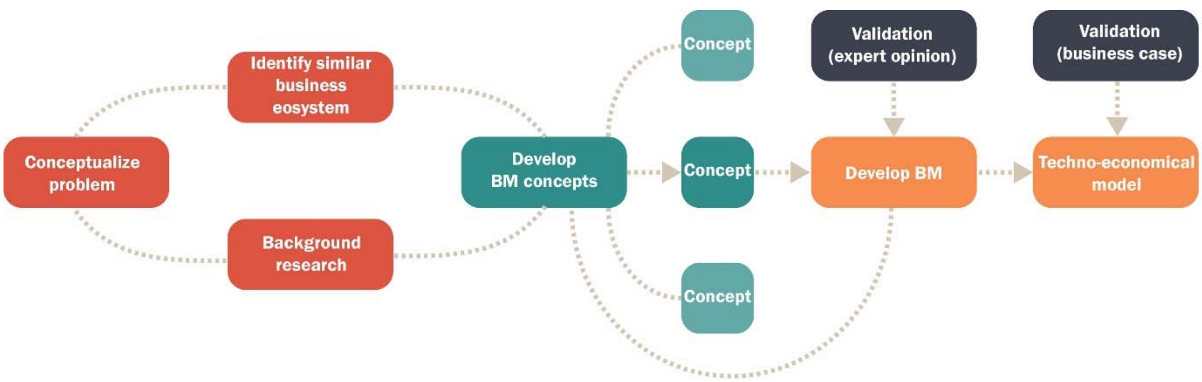

Figure 1 Research design

2.2 Research background

2.2.1 Greenhouse sector

The first step of the project is a benchmark of the greenhouse sector. The E-web model developed by Westland Infra and applied in Agriport A7 (Wieringermeer) is chosen as a benchmark. Agriport is a greenhouse cluster with a private electricity grid where the participating firms trade capacity on a trade platform. This principle of trading internally among the participating firms is used as an input to develop business model concepts for the participating firms at ETP Wijster. The concept is further developed into a techno-economic model that simulates the trading strategy to calculate the potential profits that can be earned by trading flexibility.

Our goal is to design a viable multi-commodity energy business ecosystem that includes heat and electricity. In context of this goal we benchmark how the existing greenhouse industry works as they already have achieved a viable multi-commodity business ecosystem. The greenhouse horticulture sector has been able to do that because they:

a) Use different energy sources (heat, electricity and CO_2)
b) Are both consumers and producers
c) Have energy costs as a large share of their cost structure
d) Operate in a cooperative environment with other greenhouse enterprises

In other sectors, such as industry, firms have the potential to operate in an integrated and in a cooperative setting. By benchmarking the greenhouse business ecosystem, we aim to apply the knowledge obtained in this sector to new concepts for other sectors.

2.2.2 Business models

<u>What is a business model?</u>

Academics and practitioners alike still do not agree on a common definition of business models (Gordijn, Osterwalder, & Pigneur, 2005; Jensen, 2014). However, some common ground can be found among them (Zott, Amit, & Massa, 2011). A business model describes how business is carried out (Magretta, 2002). It describes the stakeholders, their roles, and the value proposition for each of them (Timmers, 1998). It also describes the value creation, exchange, and capture logic both from a focal actors perspective as well as from the business ecosystem perspective (Chesbrough, Vanhaverbeke, & West, 2006; Osterwalder & Pigneur, 2002). In addition, it defines the business architecture in terms of the building blocks (e.g. value creation activities) that enables the value creation, exchange, and capture logic (Al-Debei & Avison, 2010).

<u>When is a business model viable?</u>

Chesbrough et al. (2006) argue that a business model is viable when all the stakeholders participating in it are able to capture sufficient value such that they are motivated to be part of it. For a business model to be viable, it also has to be technologically viable (Kraussl, 2011). A business model is technologically viable when an acceptable technological solution enables the provision of the envisioned service. In conclusion, a business model is viable when it is viable in terms of value and technology (D'Souza, Wortmann, Huitema, & Velthuijsen, 2015).

For benchmarking the business models of the greenhouse sector and designing the business model for ETP Wijster, we adopt the business model design framework for viability (BMDFV) (D'Souza et al., 2015). The BMDFV conceptualises a business model from several perspectives such as technological perspective (physical technologies architecture, and information systems architecture), business ecosystem perspective and central actor perspective, stakeholder perspective, roles and responsibilities perspective. Furthermore, the BMDFV also provides a set of configuration techniques that allows the designer to try different configuration of the business model in order to arrive at a viable business model. In addition, it also allows for combining several business modelling ontologies to highlight the different perspectives of the business model. For a detailed description and theoretical underpinning of BMDFV please refer to the paper "A business model design framework for viability; a business ecosystem approach".

2.3 Data collection

The analysis of the electricity markets and the benchmark of the greenhouse energy business models is based on a literature review, using both scientific literature and reports by organizations, complemented with expert interviews (Westland Infra, DNV-GL, AgroEnergy and Attero).

To construct the techno-economic model, electricity prices, production and consumption data were needed. We used the data for 2015 on a 15 minute time scale. Electricity production data was provided by Attero, as well as steam consumption data. For the district heating consumers, we used a simulated distribution pattern of household heat demand, provided by Hanzehogeschool Groningen. Electricity prices of the APX day-ahead market are available through a database called data stream (RUG, 2016). Imbalance market prices are published on the website of TenneT. We used the take-from-system/feed-into-system data for passive balancing. APX intraday prices are not published by the APX. Instead we used the Nord Pool data, which gives the prices of the interconnection with the Nordic region. The APX Intraday market is linked with the Belpex Intraday market and the Nord Pool Intraday market. The Nord Pool data does not give the exact results, but gives an indication of the potential profits gained on the Intrday market.

PART 1: BACKGROUND

3. Electricity markets

3.1 Introduction

The Dutch electricity sector is a liberalized market in which market actors are free to trade electricity. There are a number of markets where producers can sell their electricity and buyers can purchase the electricity needed for consumption. In practice, industrial consumers will purchase electricity on different markets, and create an optimal portfolio. The purpose of this section is to outline the different markets where power producers can trade electricity. It is important to understand how energy is bought and sold by industrial customers because it strongly influences the business model design, especially given the fact that we aim to exploit the flexibility by trading on the below mentioned commodity markets.

3.2 Forward market

On the forward markets (in Dutch: Termijnmarkt) it is possible to trade electricity for a longer time period. The most well-known forward market is Over The Counter (OTC). It is a trade platform where – with or without interference of brokers – electricity is freely traded based on bilateral negotiations. Electricity is traded in blocks of a certain capacity within a certain time unit. Blocks for base-load (24 hours a day, 365 day a year), peak load (from 7-23 hours on week days) and super peak-loads (from 8-20 hours on week days) are available for trade and can be traded per week, month, quarter or year (Oei & De Vries, 2007). Once the transaction has taken place, it is also possible to resell the electricity at later times at a better price. The prices applicable to the OTC are presented on the website of Endex. Although the transactions are agreements between two parties, and are therefore not public, a number of entities publishes trading prices for different time units (Sewalt, van Baar & de Jong, 2003). This contributes to a transparent and liquid market. To be able to trade on the OTC, market entities need to be screened and licensed by the government and need to provide a bank guarantee worth three months the purchased volume. Trading on the OTC market contains the risk that the counterparty cannot meet the obligations and parties are thereby exposed to potentially large losses (Sewalt, van Baar & de Jong, 2003).

3.3 Day-ahead market

Day ahead markets – or spot markets - are hourly markets. The Amsterdam Power Exchange (APX) for example organizes such a spot market. One can submit bids on the auction system for supply and demand of power per hour or set of several consecutive hours ('spot block orders') the day ahead of physical delivery (APX Group, 2016). Based on a supply and demand curve over all submitted bids for each hour of the day ahead, a price and volume is determined that matches supply and demand: the market clearing price and market clearing volume (Sewalt, van Baar & de Jong, 2003). There is a maximum price for selling and a minimum prices for purchasing power. Transactions are accomplished when the bid for purchasing power is minimal the market price or the bid for selling power is maximum the market price.

Other than the OTC market, transactions on the APX are made with interference of the stock exchange. APX takes accountability over the counter party risk, thereby guaranteeing the payment and delivery of the agreed volume (Sewalt, van Baar & de Jong, 2003). APX is accessible for professional parties (production and distribution companies, industrial end-users, brokers and traders) and a limited number of large consumers which are members of the power exchange. Members pay a fixed fee for the membership and a transaction fee per MWh for trading and clearing (APX Group, 2016).

The APX market is fairly predictable. Figure 2 shows the average hourly price for January between 2010-2016. The manner in which the prices develop over 24 hours is remarkably similar. Additionally, Figure 2 shows normalized daily hourly prices for January 2016. Again the price development over the 24 hours are remarkably similar. Similar patterns can be observed for other months too.

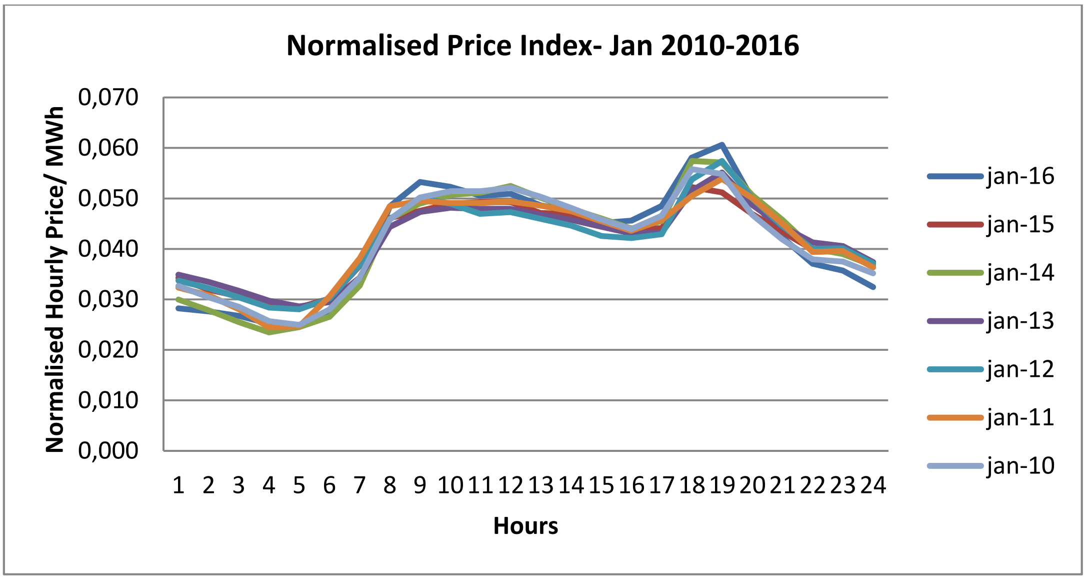

Figure 2 Normalized average price for the month of January between 2007-2016

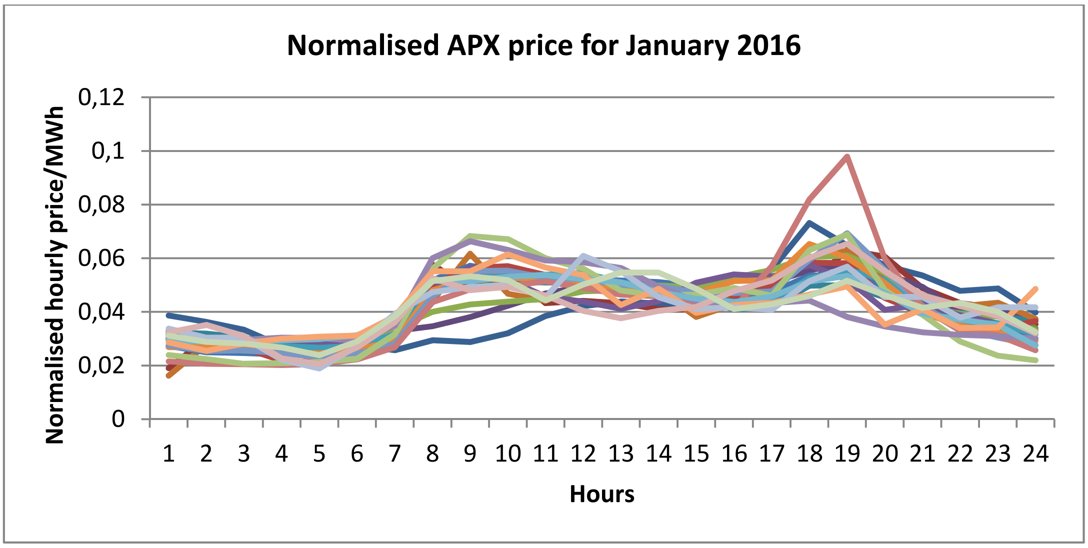

Figure 3 Normalised daily hourly price for January 2016

However, Figure 4 shows that the volatility on the APX market is decreasing. With an increase in the amount of renewables the price volatility is expected to increase.

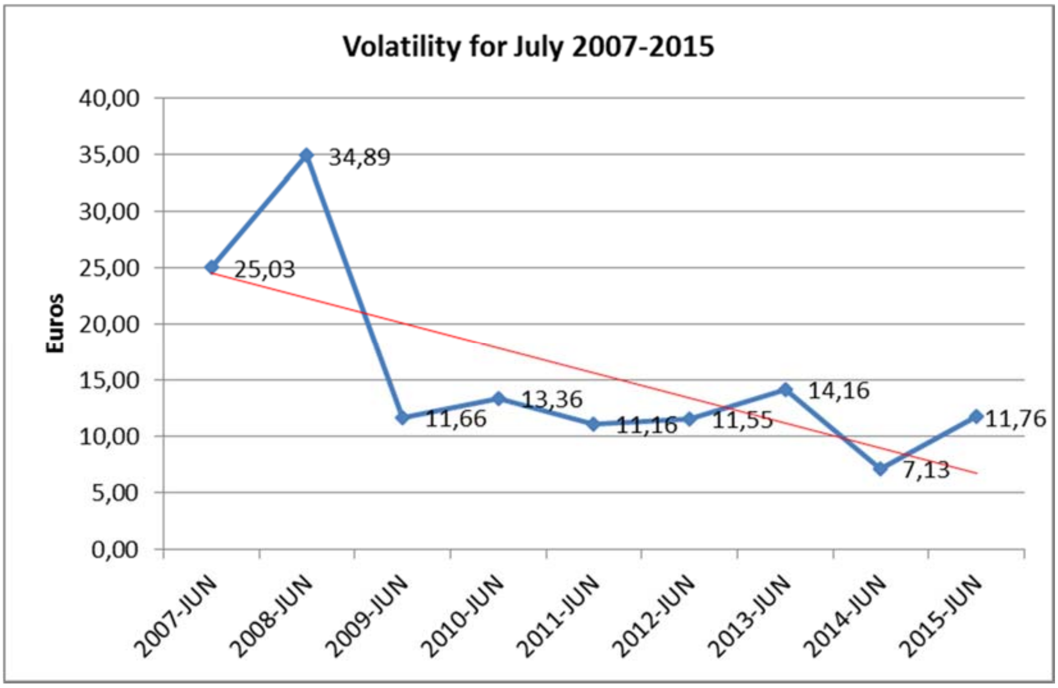

Figure 4 Volatility for July 2007-2015

3.4 Intraday and imbalance market

TenneT, as transmission grid operator, is the authorized entity to procure balancing services for maintaining the system balance (Lampropoulos et al., 2012). Power balance is maintained primarily through program responsibility. Market parties that act as a program responsible party (PRP) are acknowledged by TenneT and inform TenneT daily on the planned transactions for the day ahead. The sum of all transactions per PRP is presented in an energy schedule, so-called 'e-programs'. PRP's have the responsibility to keep their portfolio balanced for each settlement period (Lampropoulos et al., 2012). The e-programs are checked by TenneT for consistency and should be approved before operation. During operation, there will be deviations between the actual power balance and the submitted positions in the e-programs, causing imbalance. TenneT monitors the system imbalance on real-time and calls bids for operating reserves to restore the system balance if needed (Lampropoulos et al., 2012).

After the day-ahead spot market closes, there is the possibility of trading shortages or surpluses on the intraday market to avoid imbalance. On the intraday market, significantly less trading takes place than on the day-ahead market. Markets for regulating and reserve power are the next trade possibility to restore system imbalance. A well-functioning intraday market provides the possibility of optimizing the day-ahead portfolio as it is possible to change production after closing of the day-ahead market and shortly before the program time unit (PTU) starts. Producers that foresee imbalance caused by deviations from their e-program have the possibility to purchase the shortage on the intraday market, thereby preventing high imbalance costs to TenneT.

The imbalance market is meant to maintain the frequency of the grid at 50 Hz by preventing imbalance of electricity supply and demand. When speaking of 'imbalance market' we refer to the market for regulating and reserve power, which is in fact not one market but consists of several services that can be provided by electricity producers. We will outline the difference between these services and their implications for trading on the imbalance market.

There are four groups of reserve power:

1. Frequency containment reserve (primary reserve)
2. Regulating power (secondary reserve)
3. Reserve power (tertiary reserve)
4. Emergency power (tertiary reserve)

Frequency containment reserve

The frequency of the power system must be kept around the nominal value (50 Hz). To ensure a continuous balance between changes in frequency (load) and changes in production capacity (generation) the TSO calls frequency containment reserves (FCR). These are automatically controlled, fast reserves with a response time of 30 seconds. FCR is procured through two weekly auctions, for delivery in the next week. Only pre-qualified suppliers, which have closed a framework contract with their TSO, can bid in the auctions (TenneT, 2014a). To act as FCR supplier, market entities should have the agreed capacity available the full time of the contract period. Production units should also be able to run an automatic frequency control. Suppliers receive a remuneration per MW per week.

Regulating power

Regulating power is contracted or are made available through obliged or voluntary bids. Production units with a nominal capacity larger than 60 (MW) are obliged to place bids to provide regulating power for as much as they can increase or decrease their production or load (Lampropoulos et al., 2012; Frunt, 2011). The placed bids are call options: they give TenneT the right but not the obligation to call the available capacity whenever it is needed to restore power balance (Frunt, 2011). This form of operating on the imbalance (RRV) market is called *active* balancing.

Market parties can also contribute passively to the settlement of imbalance. In this case, market parties deviate from their e-programs without notifying TenneT to contribute positively to the system imbalance. The reward for passive balancing is usually lower and poses higher risks than for active balancing, thus creating an incentive to bid in the imbalance settlement system (Frunt, 2011). Information on the system imbalance is not made publicly available real-time and market parties that do not actively offer regulating power receive information of the total imbalance delta with delay (TenneT, 2004). This is a limitation to passively balancing.

The market for operating reserves is a real time market organized by TenneT. Regulating and Reserve Power Suppliers (RRPS), can submit bids to the PRP (TenneT, 2011). A bidding object consist of an up-regulating bid and a down-regulating bid. Prices are determined by a one-sided Dutch auction (bid ladder), in which a high asking price is lowered until it is accepted by the participants. The bid ladder aggregates bids per PTU. For up-regulating, the cheapest bid is used first, and correspondingly, the most expensive down-regulating bid is used first. Subsequently, TenneT charges the costs of operating regulating power at the PRP. Regulating power made available on the auction is nominated per program time unit (PTU) for the frequency control regulation (FCR), which is the mechanism to correct large control errors in the transmission grid, and can subsequently be automatically selected and controlled by the FCR body (TenneT, 2011). In case the offered regulating power is not dispatched, it will be automatically offered as reserve power. This procedure takes place on an hourly basis. In practice, prices can be very volatile. Profit can be much higher, but also the risk involved. Prices are difficult to estimate and deviations can be large.

To be able to provide regulating power, suppliers need to comply with a number of conditions, including the condition that the production unit is able to respond to the automatic steering signals and the condition to provide capacity measurements. Analogue measurements of the net-production and net-load value (in MW) are needed to verify the follow-up on the control signal (TenneT, 2011). Those measurements are taken at the point of connection to the grid with intervals of 4 seconds. The net production and load of the production unit consists of three components:

1. Forecast based on the e-program
2. Correcting actions of the production unit to limit imbalance
3. Delivery of regulating power requested by TenneT

The first two components define the *reference signal*, which needs to be sent to TenneT beforehand (TenneT, 2011). The reference signal is sent every 10 seconds for the next minute (one minute ahead). There is a time interval of 1 minute between the reference signal and the realization by the automatic control signal. The production unit follows the control signal by supplying the agreed electricity according to the regulating instruction specifications for i.e. response time, ramp rates and capacity.

<u>Reserve power</u>

Reserve power is deployed in case of extensive and/or unexpected imbalance. When the freely available balance power reaches the lower limit (about 100 MW) and the situation is expected to proceed for several time units, reserve power will be made available until there is sufficient regulating power available (TenneT, 2011). This situation occurs for instance in case a production unit drops out, creating large imbalance. Reserve power is mainly used to release regulating power when the deployed reserve power is seized too heavily for too long (TenneT, 2004). All consumers and suppliers with a production capacity larger than 60 MW are obliged to offer the volume they are able to increase their consumption resp. production levels by as reserve power. Reserve power is auctioned and rewarded similar to regulating power.

<u>Emergency power</u>

When balancing and reserve power are not sufficient to restore the balance within 15 min, emergency power can be deployed. Emergency power also supports the international power system at times of imbalance across the border. Suppliers of emergency power are contracted by TenneT and are thereby obliged to provide the contracted capacity on the call of TenneT. The contracted power must be kept available on the production unit for the entire contract period, which means that the production unit can’t run at full capacity (TenneT, 2013b). Those units are able to drastically reduce power demand or increase production in a short amount of time. Participants are contracted based on a yearly tender in which participants that comply with the basic conditions are selected on a least-cost basis (TenneT, 2013a). Compensation consists of a fixed monthly fee for availability and an additional variable fee based on metered values of supplied energy when emergency power is called for. The variable fee is defined according to a price formula which defines the settlement price equal to the highest price among: a) the marginal pricing bid +10%, or b) the APX Day-ahead price +200 (€/MWh) (Lampropoulos et al., 2012).

Every supplier of emergency power needs to make agreements with the electricity supplier and PRP. In case the supply of emergency power causes imbalance in the PRP's E-program, the called quantity is corrected on the imbalance of the PRP by TenneT. It is up to the supplier of emergency power and the electricity supplier to settle the supplied electricity.

Table 1. Overview of reserve power

	Capacity	Response time	Duration	Steering signal	Ramp up/down speed
Regulating power	4-200 MW, per 1 MW interval	30 s	Several time units	Automatic (frequency regulation correction signal/automatic generation control)	Min 7% per minute, available within 15 min
Reserve power	4-100 MW, full available capacity	15 min or later	Min-hrs	Automatic/manual	Min 100 (%/PTU)
Emergency power	min 20 MW, full available capacity	10-15 min	< 1 hr (per five-minute-periods)	Manual	Min 100 (%/PTU)

*Information obtained from Lampropoulos et al., 2012 and Tennet, 2011

3.5 Congestion management

Although congestion management is not a free trading market as the above mentioned markets, it is discussed here as it is a measure for controlling load frequency on the grid by making use of price mechanisms and market forces. Congestion management is defined as "*a system developed to prevent a situation where the electricity supply exceeds the capacity of the local or regional high-voltage grid ('congestion')*" (TenneT, 2015). When congestion occurs, there is an inability of the grid to physically deliver the energy as requested.

Congestion management is a relatively new principle in the Dutch electricity system. It is a result of a new policy that allows new entrants to be connected to the grid regardless of the available capacity on the transmission grid (TenneT, 2012). Until recently, TenneT was allowed to postpone the connection of new units until sufficient capacity was available (for instance by reinforcement of the grid or the closing of an old facility). The policy was implemented to eliminate the disadvantage of new entrants compared to incumbent market parties (TenneT, 2012). As a result, local shortages can arise in transport capacity, especially in regions where a large number producers are clustered together. Congestion problems are likely to increase in the future as the number of production units (including power plants, clusters of CHP installations and wind mills) will continue to increase (TenneT, 2015).

Congestion management is a market mechanism where producers in the congested area are incentivized not to put the contracted energy on the grid. In the Netherlands *basic dispatch redispatch* is applied to solve congestion (TenneT, 2012). Power producers in the congested area are compensated for not delivering the planned amount of electricity in order to decrease production in the congestion area. Instead, production should be increased outside of the congestion area to cover demand and fulfill contract obligations (Blijswijk, 2011). To shift the electricity production from the congestion area, producers in the congestion area place bids on the market for down-regulating and producers outside the congestion area place bids for up-regulating (TenneT, 2012). Individual production units can submit their bids through the PRP. The bids are cleared based on pay-as-bid, selecting the lowest bids for upward dispatch and highest bids for downward dispatch. Furthermore, the producer in the congested area who sold the same volume without actually producing this volume due to congestion, receives the full sale price despite the fact that they did not deliver the contracted amount of energy. Because of the lowered production, the producer saves variable costs and is therefore willing to pay the TSO (up to the amount of the variable cost) (TenneT, 2012). The costs of producing power outside of the congestion area is higher than the benefits gained from the variable costs saved by producer in the congested area. These congestion costs are borne by the TSO and are subsequently socialized i.e., they are passed on to all the end consumers through the transportation service fee.

Congestion on the transmission grid is determined prior to the actual surplus (TenneT, 2012). To be able to perform congestion management, the TSO needs to dispose of the most accurate forecasts of planned transport. The PRP's are responsible for supplying the TSO with the transport prognoses (T-prognoses) (TenneT, 2010a).

The main advantage of congestion management is that an immediate grid reinforcement is not necessary. On the other hand it can also have negative financial implications. "*Assuming that the market had originally determined the economically optimal pattern to dispatch generation units, the application of congestion management changes this dispatch order and forces a sub-optimal situation upon the system as a whole*" (Blijswijk, 2011, p5). Sub-optimal situations occur for instance when an expensive gas power plant needs to be used because a cheaper coal fired power plant needs to be ramped down (TenneT, 2012).

3.6 Pooling & aggregators

An aggregator is a market entity that joins production capacity from multiple production units and trades the capacity offered on behalf of those parties. This can have multiple advantages. It allows market entities that are too small on their own to have access to the market through these aggregators. This is also an advantage for the TSO as capacity, such as emergency power, is offered to the market that would otherwise not be offered (TenneT, 2013a). The pool participant makes agreements with the aggregator, which enables the aggregator to guarantee the required availability. Pool participants have to comply with the conditions for delivery, such as providing metering information. The participant still needs to make arrangements with the PRP and energy supplier either.

3.7 Trading flexible power at the ETP: day-ahead, intraday and imbalance

As outlined in the previous sections, a production facility has several options to sell electricity. In practice, electricity is traded on multiple markets depending on a number of factors, including price, risk portfolio, flexibility etc. In this section we will outline what implications the trade of electricity on different markets as a result of flexible energy management will be for Attero.

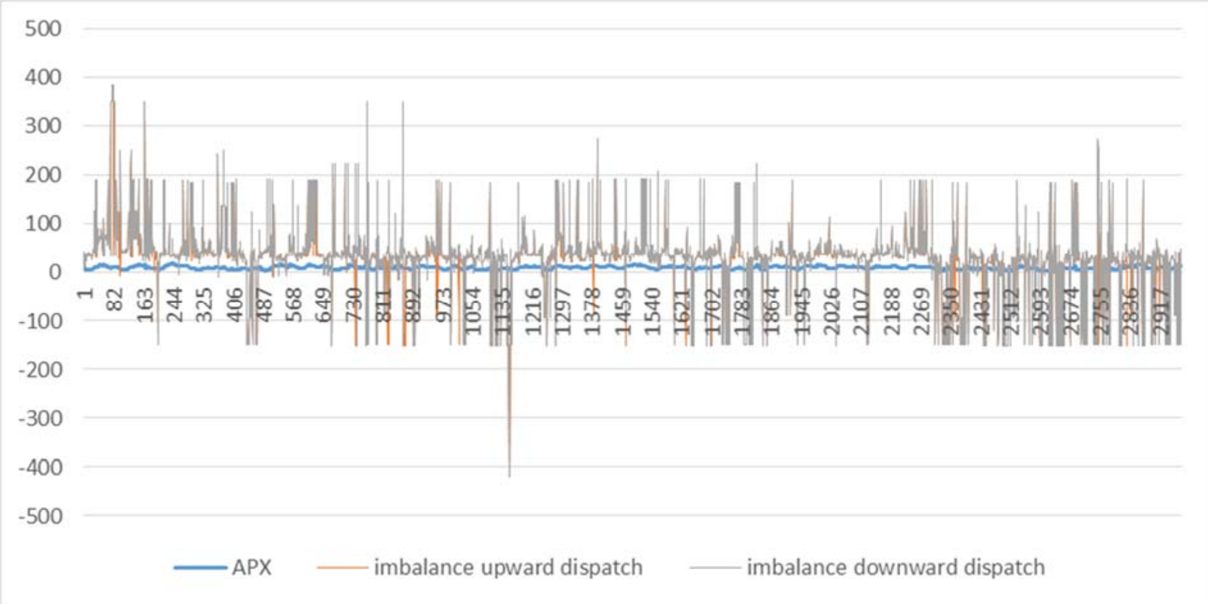

Figure 5. Electricity prices on day-ahead and imbalance.

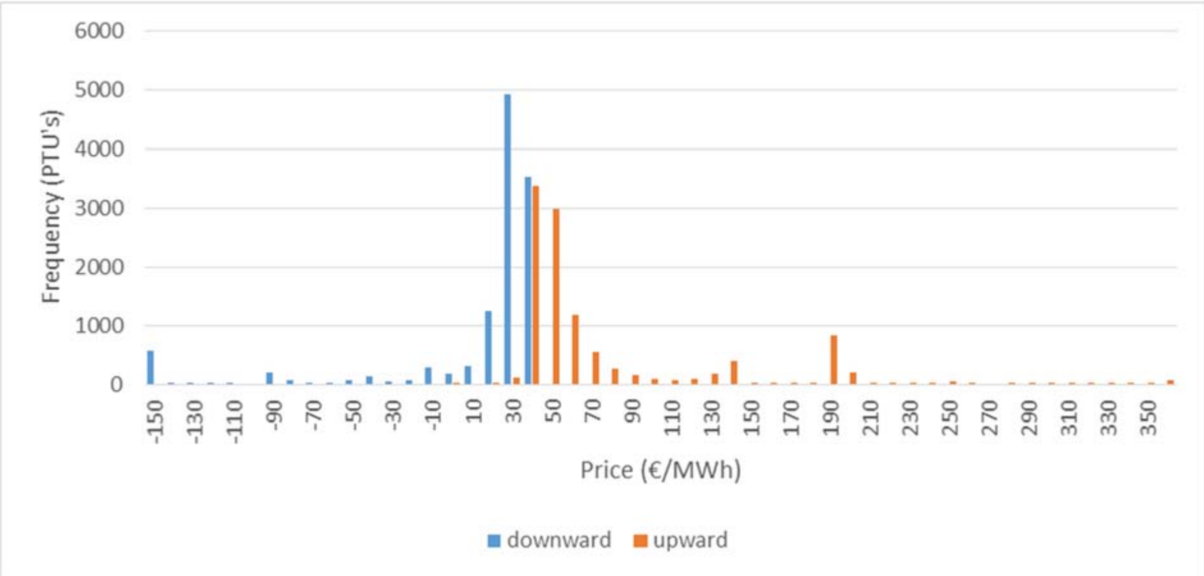

Figure 6. Imbalance prices for upward and downward regulating. The graph shows that imbalance prices for upward regulating are generally higher. The negative prices for downward dispatch represent a compensation paid by TenneT.

The imbalance market seems attractive: prices on the imbalance market are high and by up- or downward regulating extra money can be made. In case of active balancing TenneT pays a compensation for keeping the volume available for regulating power. Figure 5 shows that the imbalance prices are on average higher than day-ahead prices but also much more volatile. Although prices are attractive, the imbalance market has some downsides: 1) only a small share of the total production will be traded on the imbalance market as the contracted capacity needs to be kept available during the contract period (and cannot otherwise be used), 2) the production facility needs to be technically able to respond to control signals and have an adequate follow-up, and 3) prices for down regulating are lower than for up regulating and are on average positive numbers (see Figure 6), which means that the production facility pays this amount to TenneT. Bids for down-regulating are in general positive because production facilities will not have to produce the planned volume in case it is called by TenneT and thus have avoided production costs. Therefore, they are willing to pay a compensation. For a waste incineration plant, this situation does not occur as the waste needs to be processed also in case of down-regulating (and the steam will be wasted or used for external heat delivery) and there will be no avoided fuel costs.

One option is to be directly contracted by TenneT to provide balancing power. To be able to provide regulating power to TenneT (active balancing) a number of technical conditions needs to be met:

- Delta-setpoints
- Ramp up/down speed
- Reference signal

The production facility needs to be able to follow a control signal with a 4 s interval. These so-called delta-set points are control signals sent by the FVR (Frequency capacity regulation). The delta-set points are control instructions that inform the production unit what production is required. The delta-set points will not exceed the nominated volume and the change in set point values will not exceed the specified regulating speed (TenneT, 2014a). To follow those signals, the production unit needs to be connected to the national FVR. Production units are self- responsible for adequate follow-up of the signal. Following the delta is a correction to the E-program (TenneT, 2004). To control the follow-up of the signal, TenneT requires a measurement of the analogue net-load value and net-capacity value (TenneT, 2014a). Apart from the technical conditions, the fact that the contracted capacity needs to be kept available constantly is an important downside for Attero as processing waste is the core business.

Table 2. Advantages and disadvantages of different markets

	Advantages	**Disadvantages**	**Conditions**
APX day-ahead	Plannability (day ahead) Higher price than OTC Less volatile then imbalance	Lower price than imbalance	APX access
APX intraday	Extra trade option	Low liquidity	APX access
RRV, active, TenneT	Fixed compensation Both up and down	Stand-by capacity Low call frequency Prices for down regulating high Volatile prices	Tender 30s response time 4s control signal
Imbalance, passive, PRP	Higher price (up-reg.) Guaranteed price Both up and down	Identify changes to APX position	Service offered by PRP Follow automatic control signal
Imbalance, active, PRP	Higher price (up-reg.) (Guaranteed price) No stand-by capacity Both up and down	Identify changes to APX position	Service offered by PRP Meet technical conditions TenneT

Another option is not to provide balancing power directly to TenneT, but to make use of an aggregator. The production facility has a contract with the aggregator (usually a PRP) to offer additional capacity (compared to the APX position). The production facility receives an automatic signal from the PRP to control the production. An example of such a service is the service product FlexVast of Agro-energy. The PRP can use the flexibility to balance its internal portfolio (passive balancing through the PRP) or for providing regulating power to TenneT (active balancing through the PRP). If the available capacity is used for providing regulating power, the PRP acts as an aggregator and the production units as a virtual power plant. In this case the facility still needs to meet the technical conditions TenneT requires for active balancing (including a 30s response time).

The advantage is that electricity producers can access the imbalance market at low risk, the disadvantage is a lower profit as a result of the compensation that needs to be paid to the PRP for providing the service and for carrying the risk.

APX day-ahead and intraday markets are easily accessible for production facilities. There are no additional technical requirements that Attero needs to meet, it can be implemented in the current situation. One of the main advantages for flexible operation on the ETP Wijster of trading on those markets over the imbalance markets is the level to which production can be planned: the APX market closes 1 day before physical delivery and intraday market 1 hour before. Optimization within the day-ahead and intraday portfolio offers potential for gaining additional revenue against low investment costs.

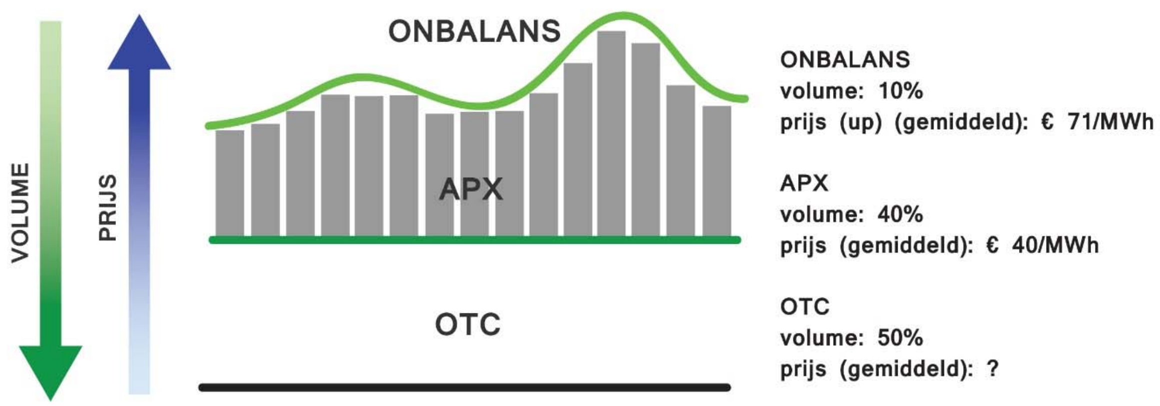

Figure 7. Breakdown of electricity sold on different markets

In conclusion, there is a general sequence of preference what markets to trade power (Bliek, F. 2016 pers. Comm. 17 Feb.):

1. APX day-ahead
2. APX intraday
3. Regulating and reserve power, active through TenneT
4. Imbalance market, passive through PRP
5. Imbalance market, active through PRP

The basic form of energy management is to trade electricity on the long term market (OTC) and the additional part on the APX day-ahead market. In more advanced forms, production facilities also trade on intraday and even imbalance markets. It requires specific expertise and services to trade on those markets. Trading on the imbalance market is still considered experimental for small production facilities.

According to this analysis we propose to research the possibilities for the day-ahead, intraday trading and imbalance market for the ETP Wijster. We will focus on optimizing the day-ahead trading and the additional trading on the intraday and imbalance markets. For the imbalance market we assume passive balancing through the PRP.

4. Energy business models in the Dutch greenhouse horticulture sector

4.1 Energy management in the greenhouse sector

The Dutch greenhouse sector enjoys a strong market position internationally. They have a reputation to be very competitive and innovative. They are continuously innovating in collaboration with the government and knowledge institutions. One of the areas where they are well known for their innovation is in the way they produce and consume heat, electricity, and CO_2 (Innovation Agro & Nature, 2007). The Dutch greenhouses have developed innovative business models for exploiting energy and related technologies. These business models are not only profitable, but also create additional value such as reduce CO2 emissions. They leverage a host of technologies such as combined heat and power units (CHPs), information communication technology (ICT), storage technologies, gas purification technologies etc., to develop viable business models. It appears to be beneficial to study these innovative energy related business models of the green houses, especially in the context of energy transition, and the urgent need to transition to a sustainable energy system. The lessons learnt by studying these business models can be transferred to other industries and situations (Zott & Amit, 2010). However, existing literature has paid very little attention to the energy business models designed and deployed by the greenhouses in the Netherlands. Therefore, the goal of this section is to map the business models of the Dutch greenhouses and derive generalisations that can be transferred to ETP wijster.

4.2 Related work

The Dutch greenhouse sector is competitive and innovative. In the past few decades they have come under increasing pressure to innovate in the energy domain due to rising energy prices, CO_2 emission reduction targets, new technologies, regulation, competition, etc. (Van der Veen, 2012) . The Dutch greenhouse sector has rapidly adopted the CHP technology that has led to an enormous reduction in CO_2 emissions, and an increase in energy and cost efficiency. As of 2013, the CO_2 emissions of the greenhouse sector were well below the 2020 targets (4,9 Mtonnes of CO2), and 56% more energy efficient since 1990 (van der Velden & Smit, 2014). In 2013, CHP technology was applied to 70% of the area cultivated by greenhouses in the Netherlands. Furthermore, the Dutch green houses have also become net producers of electricity with the help of CHPs. In addition, the increase in energy efficiency, affordable heat storage technology, and the ability to sell electricity on the liberalised markets lead to a profitable business case. However, in the past few years the profitability of CHPs has come under increasing pressure due to rising gas prices, and decreasing electricity prices (Sawin, 2015). Nevertheless, it is still useful to understand the energy business models employed by the Dutch green houses.

Greenhouses use electricity, heat and CO_2 to create an optimal environment for growing crops. Apart from the combined production of heat and electricity, the CHPs are also often used as a source of CO_2. Maintaining the climatic conditions and CO_2 levels in the greenhouses is an energy intensive process, and it forms a sizable part of the cost structure of the greenhouses. According to Velden and Smit (2014) they account for approximately 9%-22% of the cost structure of the greenhouses.

CHP's are very flexible and can easily ramp-up or ramp-down the production of electricity. Hence, they are also very attractive for the balancing market where this flexibility is extremely valuable where power plants are required to ramp-up and ramp-down in a matter of seconds. Additionally, many of the greenhouses also have heat storage that allows the farmers to store the excess heat for later use. This provides the farmers additional flexibility to shift the electricity production to times when the electricity prices are high.

The following section describes how greenhouses use energy and how some of them have even managed to make a viable business case out of producing and selling electricity.

The greenhouse and energy
Van der Veen (2012), studied the diffusion of CHPs in the greenhouse sector and identified three types of greenhouses who differ in the way they exploit energy and related technologies.

Type 1: Type 1 greenhouses were the early adapters and were primarily flower growers. They mainly used CHP's for illuminating the greenhouses in the night. The electricity produced was for internal use and the CHPs were not grid connected. They even used a part of the produced heat.

Type 2: Type 2 greenhouses allowed third parties to setup and operate grid connected CHP's on their premise. Here, the third party would remotely operate the CHP on the greenhouses premise and sell the electricity on the electricity markets. Furthermore, they would sell the heat to the farmers at a discount. In this type of business model, the greenhouse farmer would not need to invest in the CHP instead they would only need to provide the space on their premise in return for cheap heat.

Type 3: Type 3 greenhouses setup and operate their own grid connected CHPs, they usually have larger than average CHPs installed than the other two types (>0.5MWe). Type 3 greenhouses can be further categorised in three types namely: 1) Passive simple grid connected greenhouse, 2) Active simple grid connected greenhouse, (Weidenaar, Hoekstra, & Wolters, 2011) and 3) greenhouse cooperatives. The passive simple grid connected greenhouse also known as the carefree model refers to greenhouses who don't actively participate on the energy markets. They mainly sign long-term contracts with energy suppliers for stable supply of electricity and focus on their core business that is farming. The active simple grid connected greenhouses use their CHPs to sell electricity on the market (usually during peak hours) and store the heat in the heat buffers. The stored heat will be used to heat the greenhouses when the temperatures drop below the minimum required temperature. Additionally, they also offer balancing services to the program responsible parties (PRPs) via an aggregator. The greenhouse cooperatives own CHPs and form energy cooperatives. These cooperatives form an energy service company among them who will be responsible for setting up and managing an energy microgrid among the growers for example ECW (ECW, 2016). Furthermore, these energy services companies also setup and manage an internal trading platform, such the 'e-web' in ECW, that allow the greenhouses to trade energy transport capacity among themselves. Doing so allows them to optimise the use of transport capacity and keep the transport capacity costs down. In addition, they also trade energy on the energy markets, and offer balancing services to the PRPs.

For the sake of this paper type 3 greenhouses are the most interesting and the rest of this paper will focus on this type of greenhouse.

4.3 Case study

4.3.1 Roles and responsibilities

Table 3 describes the roles and responsibilities of different stakeholders involved in this business ecosystem.

Table 3 Roles and responsibilities

Roles	***Responsibilities***
Prosumer (green house farmer)	Owns energy generation assets (e.g., CHP) Uses energy for primary process i.e., growing crops Actively trades capacity and heat with other farmers Actively trades energy on markets Actively offers flexibility on the trade platforms operated by the aggregator. Offering flexibility on these platforms requires the prosumers to specify the quantity, time, ramp-up and ramp-down rates, and dates. Owns and operates energy management and CHP control information services. Negotiate and sign bilateral contract with aggregators and energy suppliers.
Aggregator	Aggregates flexibility from multiple parties and offers it to the program responsible party via trade platform Based on the trades executed they control the energy generation assets of the greenhouse farmers Offers trading platforms for energy trade among greenhouse farmers and energy markets. Offer a minimum guaranteed price to their customers in case their assets are deployed
Energy supplier	Supplies and buys energy to and from the greenhouse farmer (direct supply purchase agreements) Actively trades with the farmers via the aggregators platform and via markets such as APX All the trades executed by the farmer on the APX market and on the trade platform operated by aggregator have to be settled via the prosumers energy supplier
Microgrid operator	Setup and operate the micro energy grid that in turn connects to the grid of the distribution system operator Setup and operate e-web (capacity trading platform) Operate clearing house / billing information services
Energy Markets	A market for trading gas and electricity
Program responsible party	Active on the energy balancing market Provides balancing services to the system operator Purchases flexibility via aggregators Compose e-programs on behalf of the prosumers and submit it to the system operator (TenneT) Compose and submit T-programs to DSOs Receive v-programs and ensure that the production, and consumption schedule adhere to the v-program Inform the prosumers of the v-program Setup and operate program management information service In case of deviations from the program pay fines to TenneT Redistribute fines to the parties causing imbalance
System operator	Sets up and operates high voltage transmission system lines Provides transportation services (approx 40.000 to 60.000 euros/MW grid capacity) grid capacity

	Sets up and operates balancing markets Check e-programmes Request changes in e-programme if necessary Send V-programmes(approved e-programmes) back to PRPs Receive metering data from the DSOs and check if it matches with v-programmes and hand out fines if necessary
Distribution system operator	Setup and operate distribution system lines for gas and electricity Receive T-programs from PRPs and forecast any possible congestions Connect consumers and producers to their network Collect metering data and make it available to the relevant energy retailers and the system operator
Metering company	The metering company sets up meters at the customers location They are responsible for measuring and collecting the data related to the amount of electricity put or taken off the grid by the customer They relay this information to several parties such as the

5.4.2. Technical architecture

This Section describes the technical architecture of the type 3 greenhouses namely the simple grid connected greenhouse, the active simple grid connected greenhouse, and the greenhouse cooperatives. The technical architecture of energy systems comprises of physical technology architecture and the information services architecture of the greenhouses (A. D'Souza, van Beest, Huitema, Wortmann, & Velthuijsen, 2015; Austin D'Souza, Wortmann, Huitema, & Velthuijsen, 2015).

5.4.2.1. Simple grid connected greenhouse

<u>Physical technology of a simple grid connected greenhouse</u>

Figure 8 describes the physical architecture of a typical simple grid connected greenhouse. The greenhouse usually has a CHP installed which produces heat and electricity. The heat is directly used in the greenhouse or stored in a heat buffer. Here it is assumed that the greenhouses use all of the heat produced. The electricity produced is partially used in the greenhouse and the excess is delivered to the electricity gird (sold on the energy market, and or balancing market). The heat buffer and the boiler are used to supplement the heat demand.

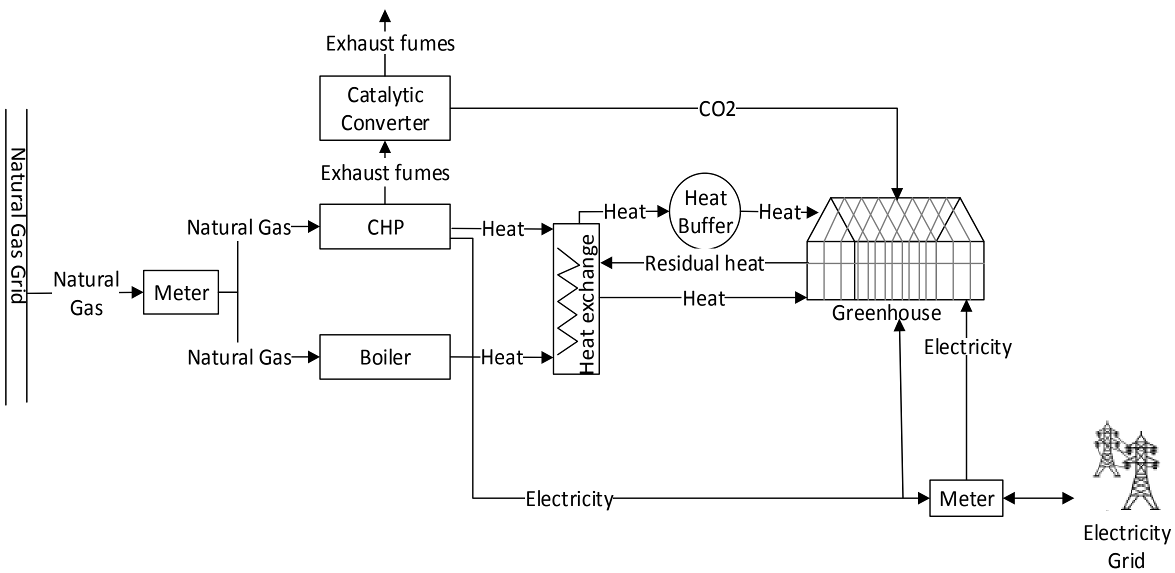

Figure 8 Physical technology architecture of simple grid connected greenhouse

The CHP also produces exhaust fumes that is then converted to CO_2 and is fed in to the greenhouses. Plants growing in the greenhouse use the CO_2 for their photosynthesis process. The main input needed for the CHP and the boiler is natural gas.

Information services architecture of simple grid connected greenhouse

Figure 9 describes the information services architecture of the carefree variant of the simple grid connected greenhouses. In the carefree model, the greenhouse signs a contract with an energy supplier who agrees to supply gas and electricity, and to purchase back the excess electricity produced by the greenhouse. An important factor influencing the buyback price of the electricity is the production schedule of the energy producer. The energy supplier handles the balancing responsibility, sourcing gas and electricity, and resale of electricity purchased from the greenhouse. The energy supplier needs to exchange information with the programme responsible party. The PRP in turn exchanges this information with the system operator who is responsible for maintaining the balance on the grid. As can be observed the PRP submits an e-program and if the e-program is approved it will be sent back to the PRP in the form of a V-programme. The metering company sets up and manages metering information service. The service mainly collects the metering data converts it in to metering information and transmits it to the distribution system operator who then makes this information available to the energy suppliers. The energy supplier in turn uses it to send appropriate bills and services to the greenhouse.

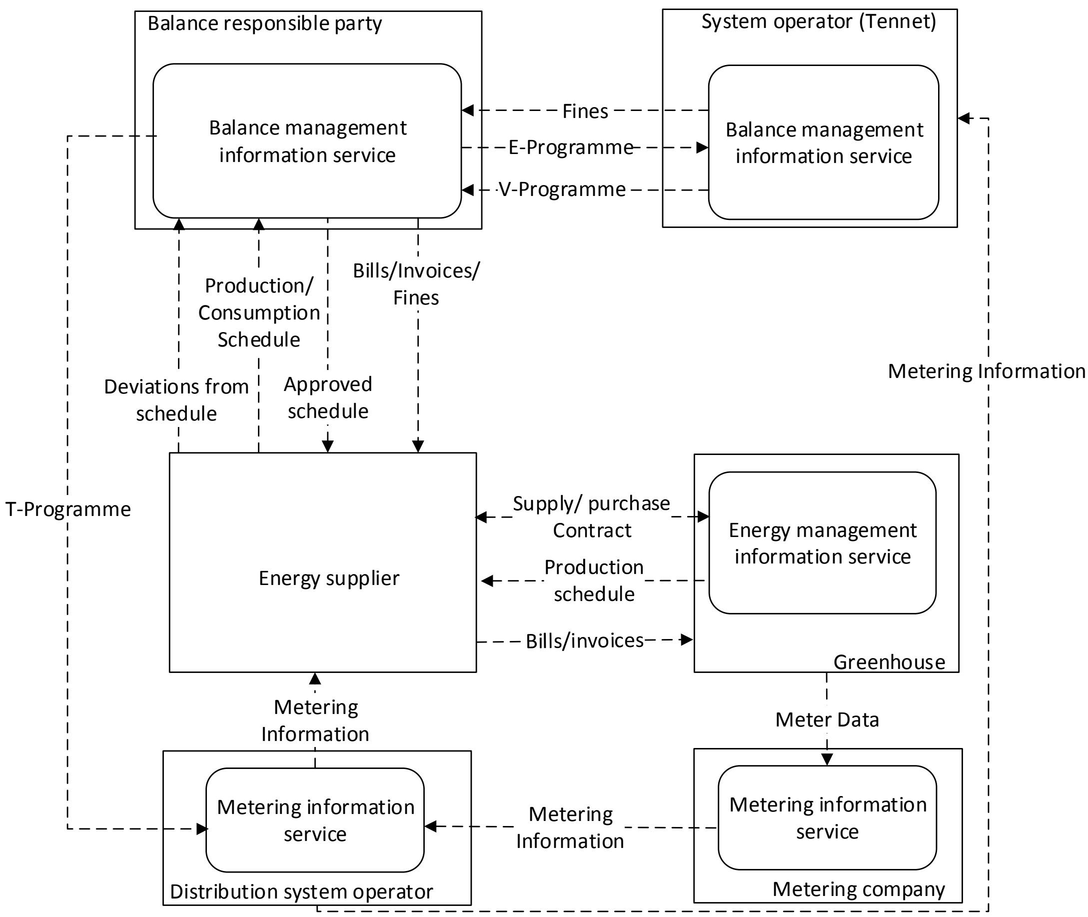

Figure 9 Information services architecture of a simple grid connected greenhouse – Carefree Model

Active simple grid connected greenhouse

Information services architecture of active simple grid connected greenhouse

Figure 10 depicts the physical technology architecture of an active grid connected green house. This is very similar to the physical technology architecture of the simple grid connected greenhouse, except for there is a control box connected to the CHP. The control box allows for switching on and off and modulating the CHP remotely. The aggregators usually sends an automatic control signal to the CHP based on the trades executed via their platform. This control signal needs to be followed by the greenhouse, which usually occurs automatically by the greenhouse' control system.

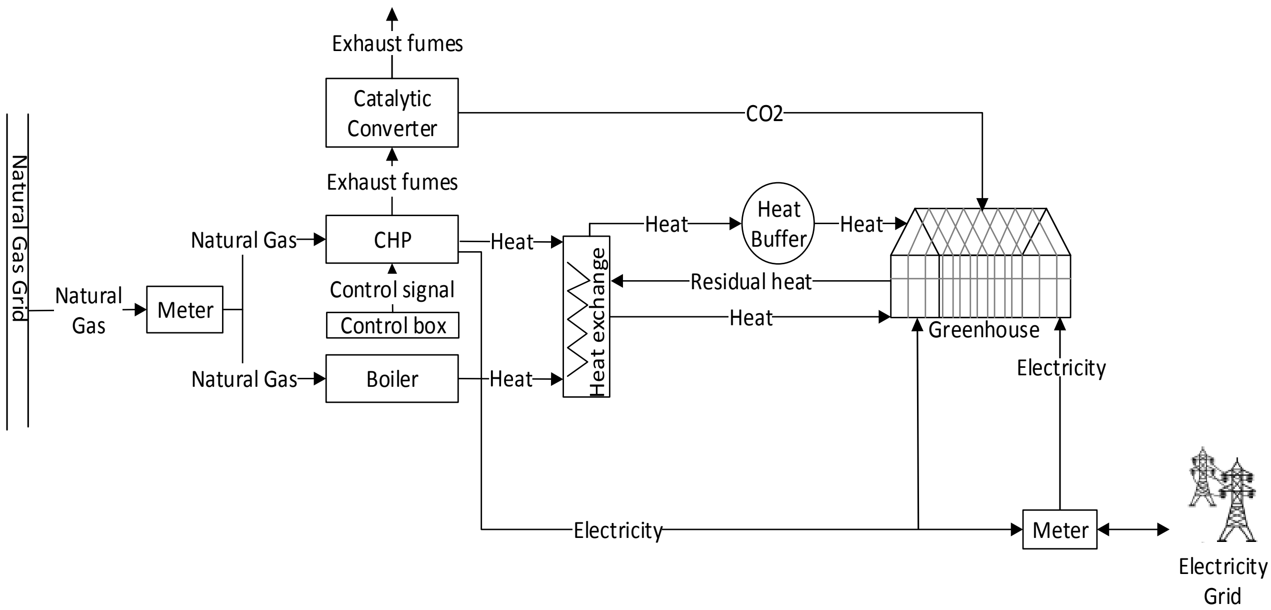

Figure 10 Physical technology architecture of an active grid connected greenhouse

Information services architecture of active simple grid connected greenhouse

Figure 11 describes the information service architecture of the active trader variant of the simple grid connected greenhouse. The information service architecture helps to understand how the information services employed by the stakeholders support the business model.

Following are the information services employed by the stakeholders:

Energy management service: The energy management service communicates with the trading platform service provided by the aggregator. It receives and displays information on status of the buy and sell order placed by the farmer, and price information. It is also capable of placing buy and sell orders automatically based on the trading preferences provided by the farmer. The decision to place a bid on the market is a complex function of parameters such as current market position, heat buffer capacity, price of electricity, internal heat demand, internal electricity demand, CO_2 demand, available transport capacity, and price predictions. Furthermore, the energy management service also facilitates the generation of energy production and consumption schedule and the service sends it to the programme responsible party. The energy management system also receives and stores the approved production schedules and informs the PRP in case of deviation from the schedule.

CHP controller service: The CHP controller service controls the CHP. The controller switches the CHP on and off. Furthermore, it can also ramp up or ramp down the production of electricity and heat on the CHP. The CHP controller receives a control signal from the energy generator management service from the aggregator.

The *aggregator* operates the following information services:

Trading platform service: The trading platform service provided by the aggregator enables the greenhouses to trade on multiple markets such as day-ahead markets, intraday markets, and the imbalance market (via their PRP). The trading platform service aggregates and provides the status of the buy and sell orders, and the price information from the various markets. Furthermore, it receives the buy and sell order from the energy management service of the greenhouses and places the bids on the respective markets in an automated manner. The trading platform service is also of interest to PRPs because the greenhouse farmers offer their flexibility on the trading platform. The PRPs can in turn leverage this flexibility offered by the greenhouse farmers on the platform to trade on the balancing and congestion markets operated by TenneT or balance their own portfolio to avoid fines. The greenhouse farmers cannot directly trade on the balancing and congestion markets because they usually do not meet the criteria to directly trade on the markets operate by TenneT. The trading platform can also be used for contracting long term energy supply and purchase contracts.

Energy generator management service: This service controls the CHPs of the greenhouses. The energy generator management service sends a control signal based on the trades executed by the greenhouse farmer.

The *Transmission System Operator (TSO),* in this case TenneT, operates the following information services:

Balancing market /congestion market service: The main goal of this service is to help TenneT manage the balance of the grid. At any given point in time, the amount of electricity put on the grid should be equal to the electricity taken off the grid. Furthermore, it is not always possible to put any amount of electricity or consume any amount of electricity from the grid because of the grid limitations i.e., transport capacity. This process of making sure that the amount of electricity put on the grid and the amount consumed from the grid are equal at any given point in time is called balancing the grid. The balancing market allows the BRPs and other licensed parties to put more or less electricity, and consume more or less electricity than what was specified in the e-program (TenneT, 2014b).

The following information service is operated by the *program responsible party*:

Programme management information service: The main function of the programme management information service is to collect/ predict production and consumption schedules and forecast an e-programme. The balancing management service then transforms this information in to e-programs[1] and submits it to the system operator (TenneT). The system operator then checks the e-program for consistency and sends back a finalised program back to the PRP. The finalised program sent back to the PRP is called the V-program. The PRP then sends back an approved schedule to the greenhouse

[1] E-Programme contains the amount of electricity that a connected party intents to take from or put on the grid per fifteen minutes (TenneT, 2014a).

farmer. Furthermore, the PRP also sends a T-programme[2] to the distribution system operator (DSO). The T-programme is used to predict any problems related to congestion (TenneT, 2010b). In addition, the system also relays back information regarding any fines related to unbalance incurred by the greenhouse.

Balancing information service: The balancing information service main task is to trade on the balancing / congestion markets operated by TenneT. The PRP's trade on secondary, and tertiary balancing markets, and they also passively contribute to balance the grid (Boots, 2011; Frunt, 2011). For the rest of this section, we will focus on the passive contribution because the greenhouses mainly contribute to passive balancing. Passive balancing occurs when parties not selected by TenneT to balance the grid respond to the market mechanism of the imbalance market. For example, let's assume that there is too much energy being taken off the grid than is being put on the grid. TenneT then tries to select parties who can produce additional energy to put on the grid via the secondary balancing mechanism and in rare cases via tertiary balancing mechanism. However, parties not selected by TenneT can still be rewarded by the Dutch balancing system by causing an imbalance in the opposite direction of the grid imbalance, i.e., in this example the party contributing to passive balancing is rewarded by putting more electricity on the grid. Nevertheless, this is not risk free. When the party decides to take part in passive balancing, but ends up causing imbalance in the same direction as the current state of imbalance of the grid, i.e., in this example consuming more energy or putting less energy than initially promised they will be penalised. Therefore, in order to participate in passive balancing activity it is required of the PRP to have a good overview of the current state of market and the ability to predict the state of the grid. The PRP's have access to the trading platform operated by the aggregators. They deploy the electricity generators based on the bids place by the greenhouse farmers via the aggregator (Frunt, 2011). This happens every program time unit (PTU) i.e, every 15 minutes. Only after the PTU has elapsed it becomes clear if they have made a profit or incur a fine.

The System operator (TenneT) operates the following information services:

Balance management information service: The balance management information service collects all the E-programmes and checks them for consistency. An approved E-programme, also known as V-programme, is then sent back to the PRPs. In addition, the system also collects the metering data from the DSO and checks for any deviations from the approved programmes it then calculates the fines accordingly and informs the PRPs.

Balancing markets: TenneT operates the balancing markets and the congestion market. The balancing market is open to all market parties via the program responsible parties and a trading platform. This platform receives the bids from the market parties, and publishes the imbalance price in real-time. Furthermore, it also informs parties who have been actively selected by TenneT to provide electricity to balance the grid. The parties not selected by TenneT to provide electricity to balance the grid can still choose to passively balance the grid at their own risk. The bids can have minimum bid size of 4MWh and max bid size of 200MWh.

[2] A T-programme is an estimate of the amount of electricity the connected party intends to put or take off the grid. It is similar to the E-programme, but there is no risk of fines in case of deviating from the T-programme (TenneT, 2010b).

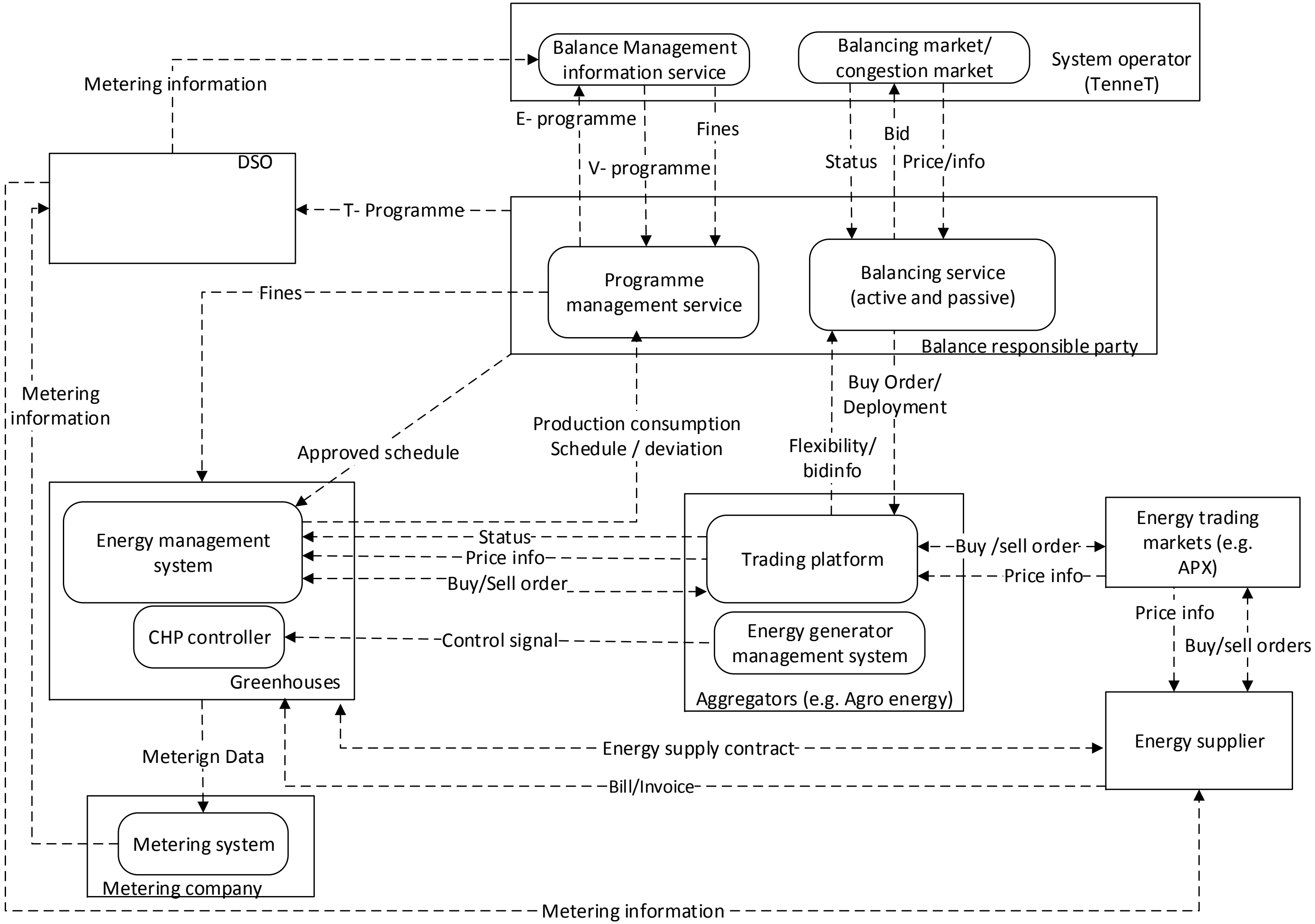

Figure 11 Information services architecture of a simple grid connected greenhouse – Active trader model

The metering company operates the following information service

Metering information service: The metering information service either automatically or manually collects the meter data from the greenhouses, and the data is relayed to the DSO (NEDU, 2014).

Additionally, there are three other actors that operate their proprietary information services in this business ecosystem namely DSO, Energy supplier, and Energy markets. However, we have chosen not to make these explicit as they are beyond the scope of this paper. We have chosen not to model the information services operated by these actors for the sake of simplicity.

5.4.2.2. Greenhouse cooperatives

Physical technology architecture of greenhouse cooperatives

Figure 12 describes the second category of type 3 of greenhouses. These are greenhouses that usually form a cooperative and are connected to a microgrid. The microgrid in turn in connected to the grid of a system operator (TSO or DSO). The physical technology architecture of each individual greenhouse connected to the microgrid will be similar to that of a simple grid connected greenhouse (see Figure 8). The cooperative usually forms an energy services.

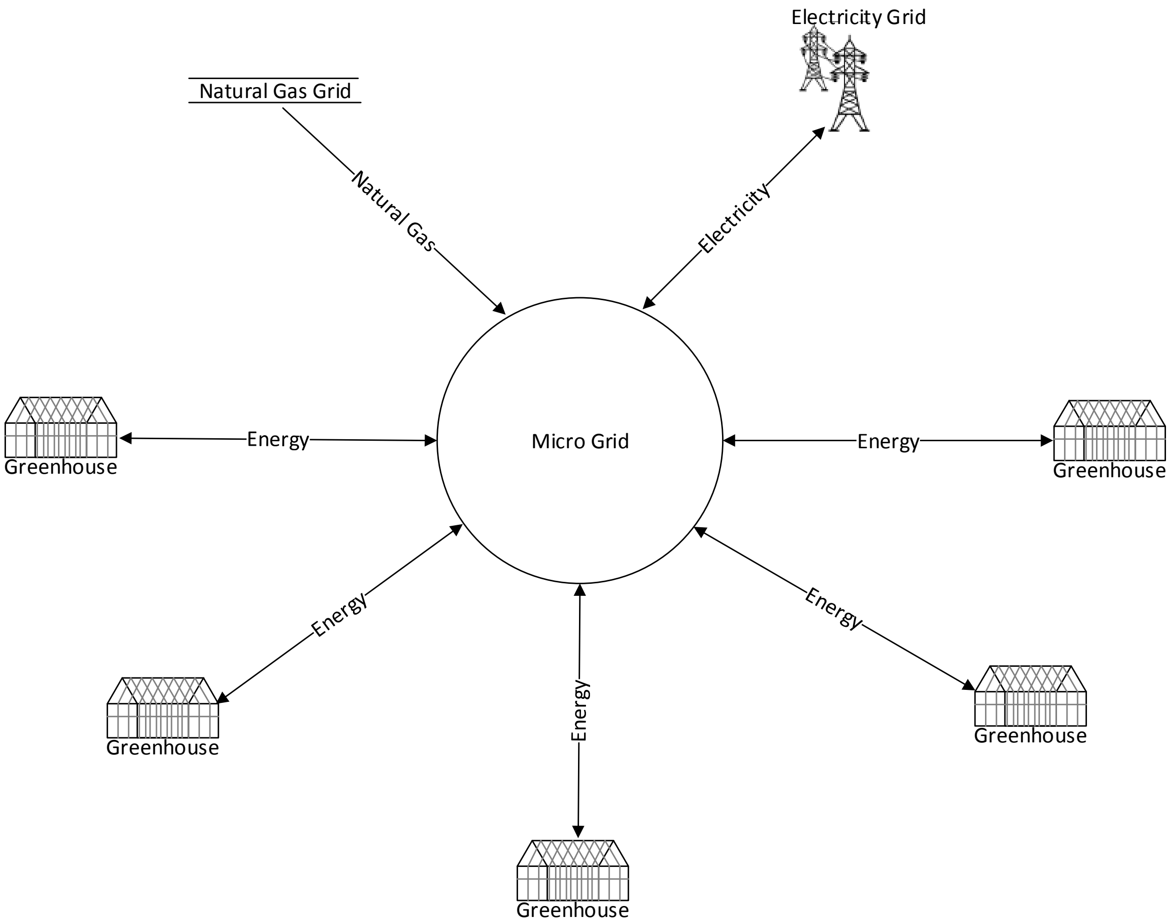

Figure 12 Physical technology architecture of greenhouse cooperatives

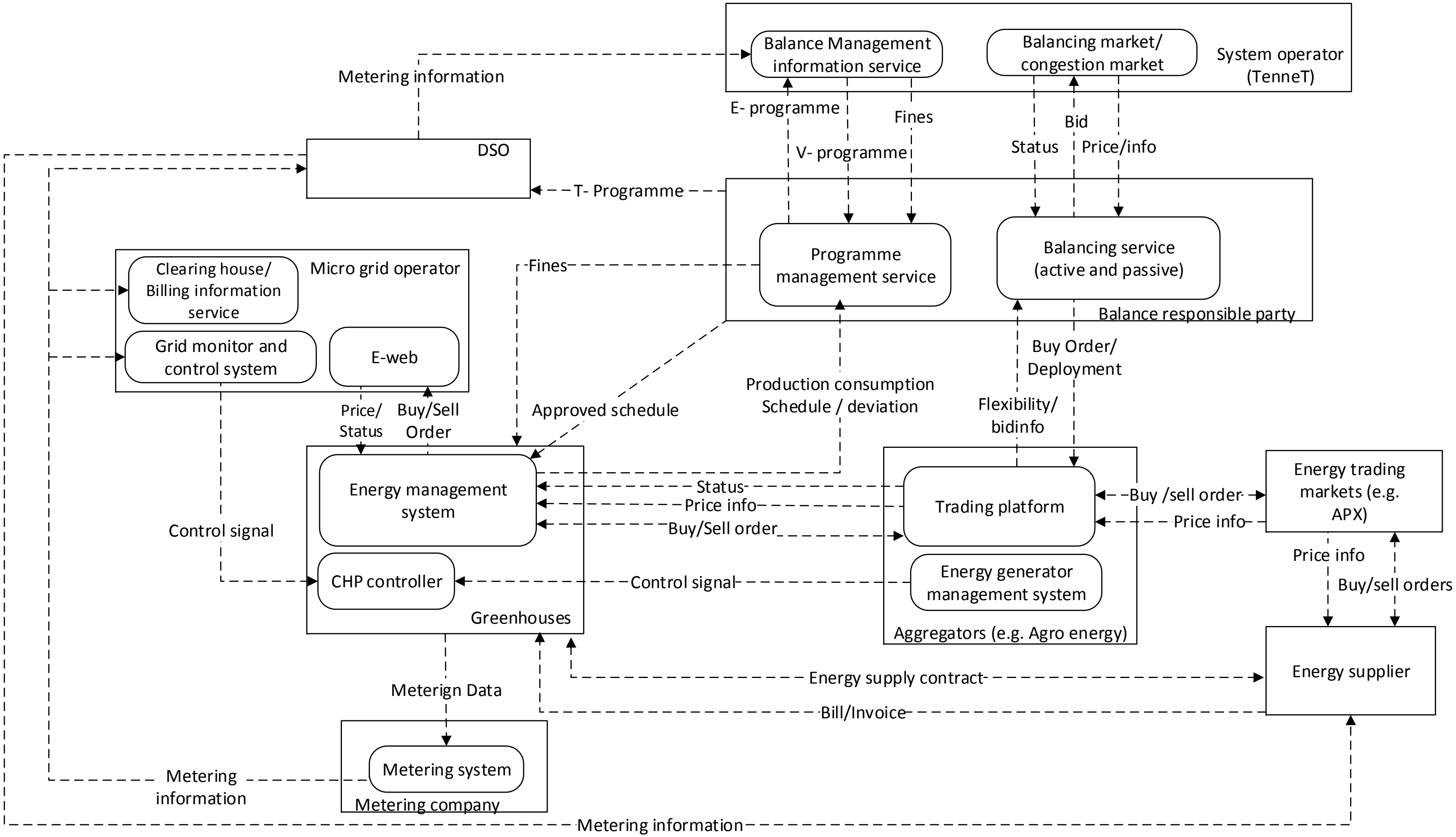

Figure 13 Information service architecture of the greenhouse cooperatives

Information services technology architecture of greenhouse cooperatives

Figure 13 describes the information services architecture of the of the greenhouse cooperatives. Here it can be observed that most of the stakeholders and the information services remain the same as in the case of active simple grid connected greenhouses. However, there is a new role called 'microgrid operator', who owns and operates two new information services. Furthermore, the information services in owned and operated by the greenhouses communicate with the information services of the microgrid operator. Therefore, the rest of the section will mainly focus on the new role and the information services owned and operated by them. Additionally, this section will also focus on the changes compared to the active simple grid connected greenhouse.

E-web: e-web is a trading platform that allows the greenhouses to trade electricity transport capacity and heat among themselves. In order to facilitate the trade, the e-web communicates the commodity prices (electricity transport capacity and heat) to the greenhouses, and it executes the commodity buy/sell orders from the greenhouses. Furthermore, it communicates the information about all the executed orders to a clearing house/billing information services. However, since this is an internal communication within the microgrid operator we do have not explicitly modelled this interaction. In addition, this system is aware of the total electricity trade capacity and the heat contracted by each greenhouse and it ensures that the greenhouses stay within the contracted capacity. It does so by constantly monitoring the amount of energy put and taken off the grid by each greenhouse and the amount of heat consumed by each greenhouse. Furthermore, it also aligns this activity with the trades executed on e-web. In case of greenhouses, exceeding their contracted amount of electricity transport capacity e-web automatically sends a control signal to the CHP to reduce production such that the production will not exceed the contracted capacity.

Clearing house/Billing information services: This information service ensures that the all the trades are executed and the actual consumption match is accounted for. Furthermore, it also ensures that the greenhouses are billed correctly and on time. In order to this they receive the metering information relayed by the metering service. Furthermore, they also get information on all the trades executed on the E-web.

In addition to the above new services, there are some minor changes that take place with services such as metering service and CHP controller information service. The metering company also relays metering information to the micro grid operator. Furthermore, the e-web operated by the micro grid operator also sends control signals to the CHP of the greenhouse. In case of conflict between the aggregators control signal and the e-webs control signal E-webs control signal takes precedence.

5.4.3. Business model from the business ecosystem perspective

5.4.4. Simple grid connected greenhouse

The simple grid connected greenhouses are not actively trying to optimise their energy costs or earn money on the energy market. From Figure 14 the greenhouse farmers prefer to source energy from energy suppliers on a long-term basis. They also sign long-term electricity supply contracts for a fixed price and they also outsource their programme responsibility to the energy supplier who then in turn outsource it to PRPs. The metering company meters the amount of energy taken off the grid and put on the grid and supplies this information to the DSO. The DSO offers transportation service to the prosumers for a fee. The TSO offers transportation services to the DSO for a fee.

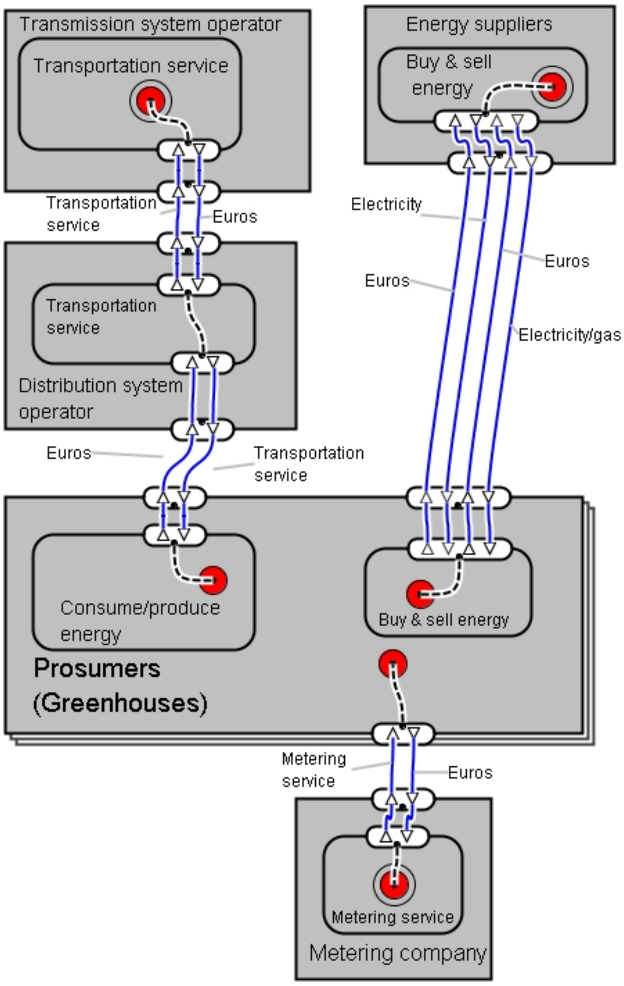

Figure 14 Simple grid connected greenhouse

5.4.4.1. Active simple grid connected greenhouse business ecosystem

Figure 15 depicts the business ecosystem of the simple grid connected greenhouse. The major difference between greenhouse cooperatives and the active simple grid connected greenhouse is that greenhouses operate individually and they do not own and operate their own private micro grid. This has the following implications:

- The microgrid operator is absent in this business ecosystem. The greenhouse is directly connected to the DSO's grid. Therefore, the greenhouses do not cooperate among themselves to optimise the use of the grid.
- The metering company does not share metering information with the micro grid operator

For a complete description of the business ecosystem see section 5.4.4.2

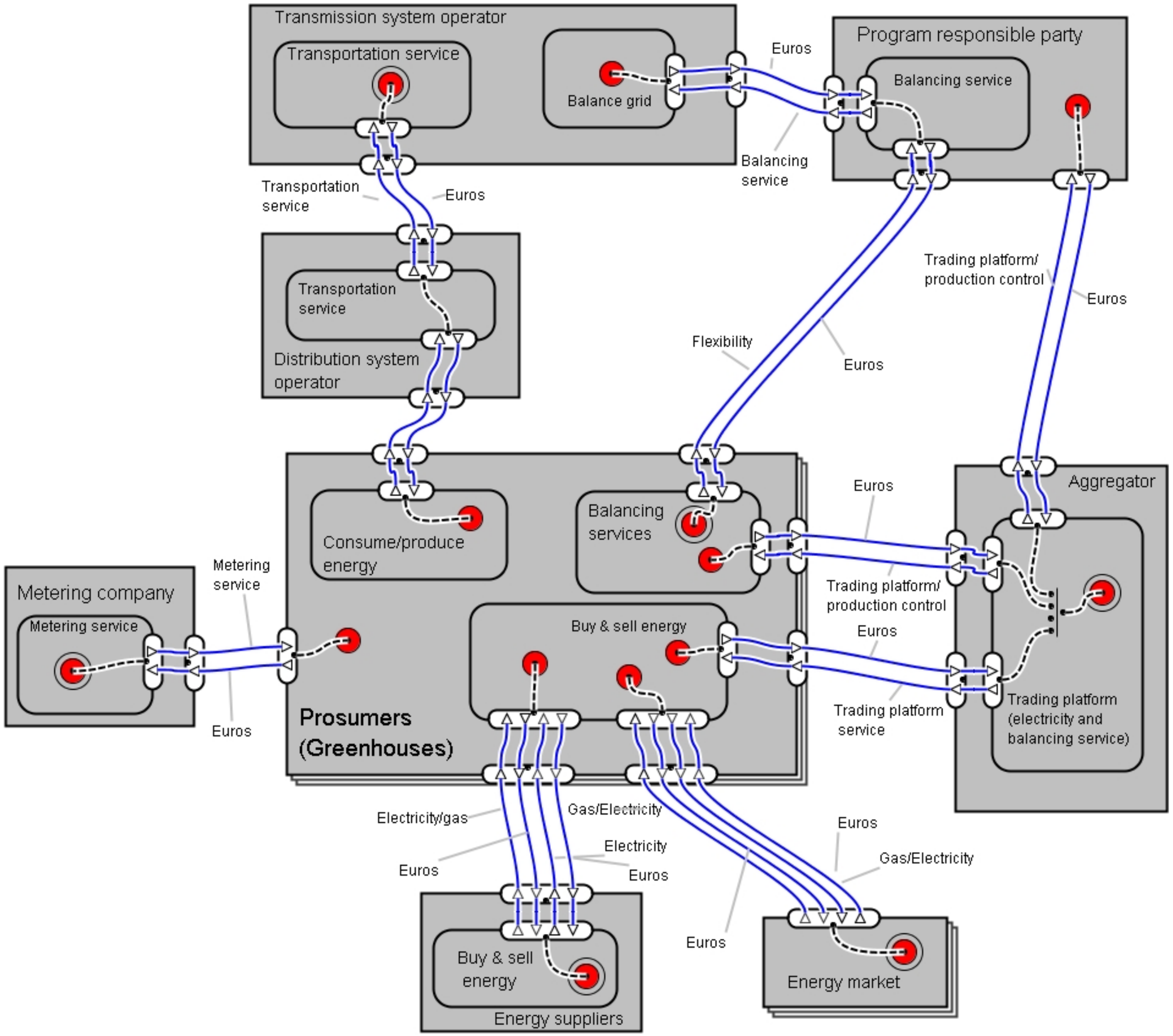

Figure 15 Simple active grid connected greenhouse business ecosystem

5.4.4.2. Business model of the greenhouse cooperatives

Figure 16 depicts the business ecosystem of the greenhouse energy cooperatives. There are about nine actors involved in this business ecosystem each playing a separate role.

The prosumers role is played by the greenhouses. In addition to trading electricity via an aggregators platform (as described in the previous sections) the green houses also trade transport capacity and heat internally on the micro grid. The greenhouse farmers also try to optimise their energy transportation costs and heat costs by trading transport capacity and heat among themselves on a trading platform like e-web. The trades executed on the e-web is then monitored and billed appropriately by the microgrid operator. Additionally, they consume the transportation services provided by the microgrid operator.

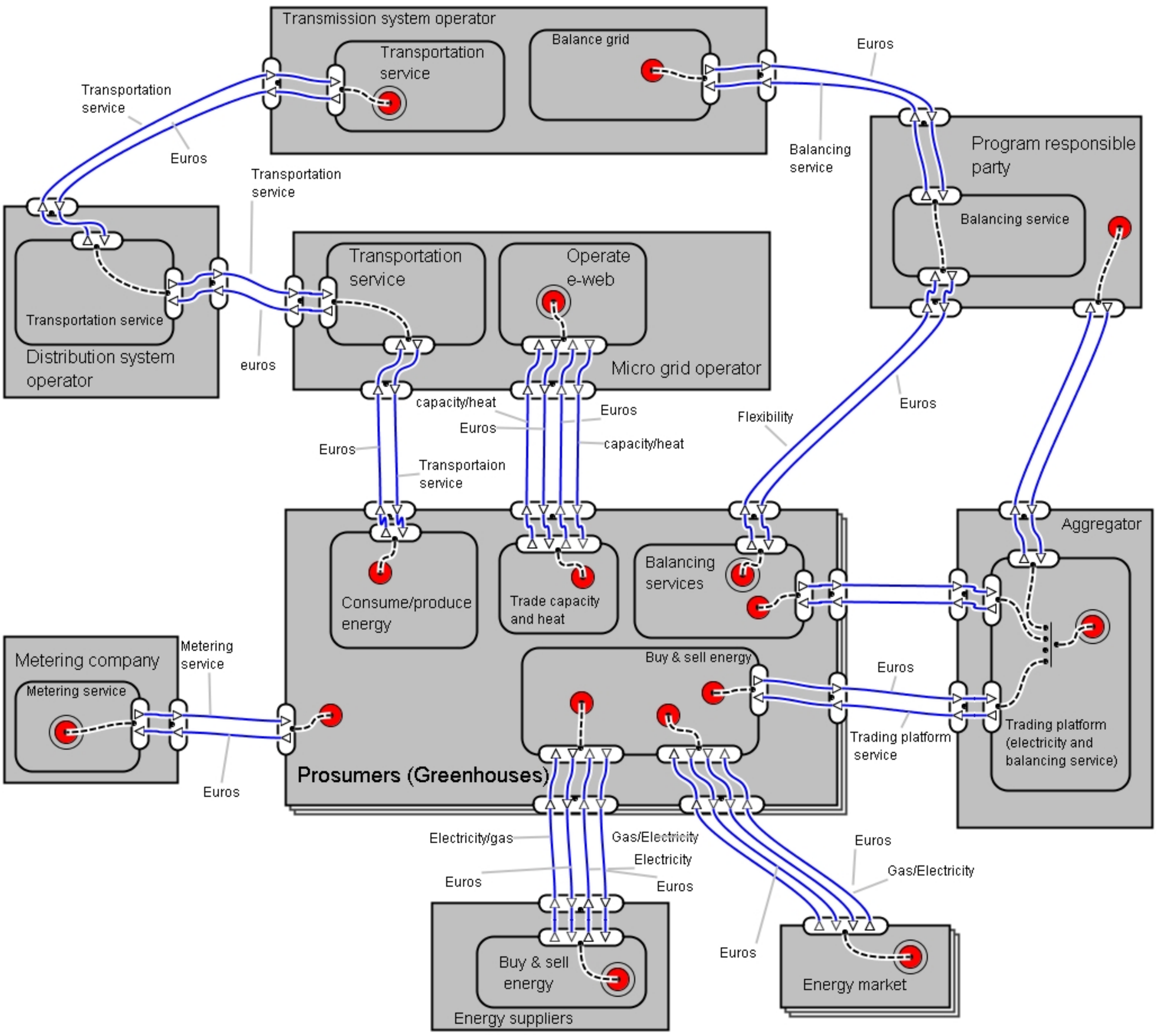

Figure 16 Greenhouse cooperative business ecosystem

The greenhouses also consume the metering services offered by the metering company. This is an essential service that meters how much natural gas, electricity, and heat is taken from the grid or put back on the grid. The information provided by the metering service is essential for billing purpose.

The role of the energy supplier remains unchanged in the greenhouse cooperative setting.

The energy markets such as APX offers trading platforms to energy traders. However, in this case the prosumers trades on the energy markets via the trading platform provided by the aggregator. It is also possible that they trade energy directly on the APX directly but for the sake of simplicity we have not modelled all the possible configurations

The micro grid operator offers transportation services and a trading platform to the prosumers for a fee. Operating the e-web also involves monitoring the usage of the grid and making sure it complies with the contracts and the trades executed on the e-web. The micro grid operator in the context of this study was jointly owned by the greenhouses. The microgrid in turn is connected to the DSO's grid.

The role of the DSO's, TSO's, PRP's, metering company, and the aggregators remains unchanged for more information please refer to the previous sections.

PART 2: A FLEXIBLE BUSINESS MODEL FOR THE ETP

6. A multi-commodity business ecosystem for the ETP

As mentioned in the introduction, the ambition of ETP is to realize an intelligent and economically viable business ecosystem where firms collaborate and trade electricity, heat, and *flexibility*[3] in order to create value. The aim is to create a business model that leverages the flexibility of the firms located at the ETP by changing the ratio of steam turned to electricity or heat depending on the electricity prices on different markets. This section elaborates on designing a business model ecosystem specific for the ETP that leverages the flexibility of the firms in order to capitalise on the arbitrage opportunities that exist on the day-ahead, intraday and the imbalance market.

6.1. Similarities and differences with the greenhouse business models

Since the greenhouses already leverage their flexibility to capitalise on the arbitrage opportunities on the OTC, APX, and imbalance markets it is logical to review the similarities and differences between the greenhouses and ETP. Furthermore, it is important to distil a set of lessons learnt that will provide vital input the design and validation of viable business ecosystems.

Table 4 Similarities and differences between ETP Wijster and the greenhouses

	ETP Wijster	**Greenhouse clusters**
Similarities	Industry cooperates to optimize energy costs	Greenhouses work together to optimize energy costs
	Establishing and managing a private heat network in a cooperative setting	Establishing and managing private electricity, gas and heat networks in a cooperative setting
	Flexibility is key in the value proposition. Firms are capable to adapt processes to market demand	Flexibility is key in the value creation. Greenhouses are capable of adapting the energy demand to energy prices and compensations for balance services.
Differences	Business cluster consists of 2, possibly 3 firms.	Greenhouse cluster consists of multiple firm (Agriport counts 7 participants)
	Attero is the only producer, firms are only consumers	All participating firms are prosumers
	Optimalization of energy trades.	Optimalization of local-national grid connection (transport costs)
	Attero is the only firm that can trade on the electricity market.	All participating firms trade on the electricity market individually.
	Flexibility is dependent on partner firms.	Flexibility is a function of internal business processes.
	Attero offers high quality steam for industrial end-users, which is hard to store.	Greenhouses produce and consume lower temperature heat, which is storable.

Lessons learnt:

- The order in which to approach the markets day-ahead first, intraday next, and balancing as a final option
- Active energy management is necessary where firms plan their consumption and flexibility in advance

[3] Flexibility is defined as the ability of the firms to shift their demand for energy in time and or increase or decrease their consumption of energy. It also refers to the ability of some firms to produce different forms of energy such as heat and electricity.

- Close collaboration with the PRP is necessary to actively trade on the balancing market
- An electronic trading platform is necessary to offer flexibility/ trade energy among the companies
- A smart control system(information services) is needed that can control the flow of energy and physical infrastructure based on the trades executed on e-web and the trades executed on the markets
- A new role called the aggregator is necessary that will control the production of heat/steam based on the trades executed on the various markets

6.2. Business model concepts

The ETP has a 54 MWe waste burning plant (Attero) that produces heat and electricity. Companies located on the ETP can source heat of different qualities from Attero. The companies enter into long-term contracts with Attero for the supply of heat, through which they have guaranteed delivery of the contracted quantity and quality of heat against a fixed price. However, when the heat consumer(s) are able to adapt their heat consumption following the electricity prices, the ETP as a whole could gain additional profit from the flexible trade of electricity. As a result of the flexibility, the amount of electricity sold when the prices are high can be maximized and vice versa, the heat sold can maximized when electricity prices are low.

After studying the business models of the greenhouse sector and the electricity markets, we reflected the lessons learnt on the situation of the ETP Wijster. Whereas the greenhouse clusters trade capacity, the partner firms at the ETP trade flexibility. Attero is the central stakeholder that is both connected to the electricity markets and to the trade platform. Attero places an offer on the E-web whenever the prices on the electricity markets are profitable and each firm individually places bids. Where the bids and the offer match, there is a deal. The planned heat consumption is still met by the contract between Attero and the heat consumers. The flexibility traded are deviations from the contracted heat consumption.

Early on in the design process it became clear that several variants of the business model were possible. In order to narrow the scope further, we developed four high-level business model concepts. We presented these concepts to the relevant stakeholders and received feedback on how to further develop flexible business model. Showing the possible options opened a dialogue among the stakeholders and lead to a consensus about the business model concept we should further investigate. The choice of the business model concept was based on which business model they were most likely to implement.

In this section we briefly introduce the four high-level concepts presented to Attero. The business model concepts include four electricity markets: forward, day-ahead, intraday and imbalance market. The starting point is for all four business models is that there is an internal trade platform that we call ‘E-web’.

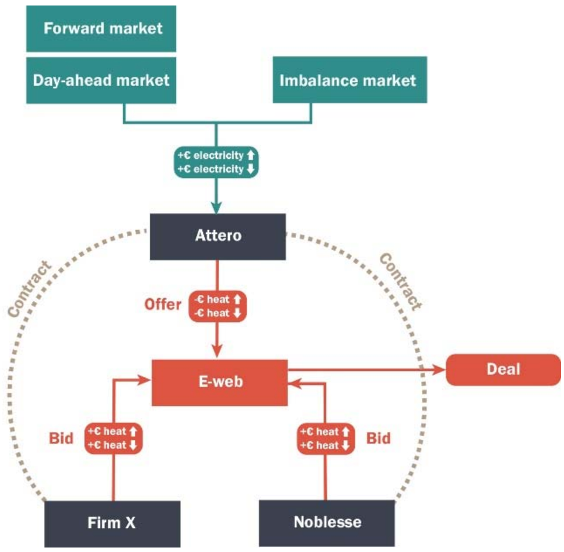

Figure 17. Basic business model concept

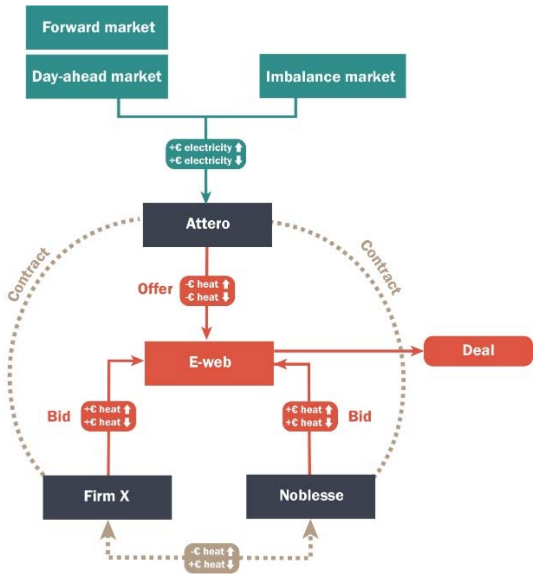

Figure 18. Business model concept with internal trade

Figure 17 represents a fairly simple version of the business model. Here, all of the flexible consumers namely Noblesse and Firm X (fictive firm) will submit their flexibility, and the price for their flexibility, to Attero via E-Web. Based on the received bids, Attero will then take positions on the APX day ahead, and intraday markets. Additionally, Attero will also submit bids on the external aggregator's platform. The aggregators in turn provide this flexibility to PRPs who trade on the imbalance markets. Depending on the trades executed by Attero and flexibility engaged by the PRPs the steam delivery to the flexible consumers will be modified. Furthermore the revenues will be shared based on agreements among the stakeholders.

Figure 18 presents a variant of the business model concept presented in Figure 17. Therefore, it incorporates all the working principles of the business model concept depicted in figure 17. However, in this case the flexible consumers also trade heat among themselves. This provides the heat consumers located at ETP Wijster with more flexibility. The business model depicted in Figure 17 and Figure 18 are not mutually exclusive but one business model can easily be converted to other. However, the business model depicted in Figure 17 is a little less complex in terms of operations and management.

Figure 19 depicts a business model that is again a variant of the business model depicted in Figure 17. Hence, it incorporates all the working principles of the business model depicted in Figure 17. However, in this business model every actor in the business ecosystem owns and operates a storage facility that allows them to more flexible.

Figure 20 depicts the most complex business model concept. It is a variant of the business model depicted in Figure 17 and figure 19. However, in this case in addition to the storage technologies the firms at ETP Wijster not only own and operated a private heat grid, but they also own and operate an electricity grid. The flexible consumers, and Attero would trade flexibility as in the business model depicted in figure 17 via the internal trade platform. Additionally, the firms at ETP Wijster would also trade electricity transport capacity similar to the greenhouses. The capacity will be traded among the firms located at ETP Wijster. This will allows them to optimize the total electricity transport capacity that they contract from the DSOs further lowering their energy costs.

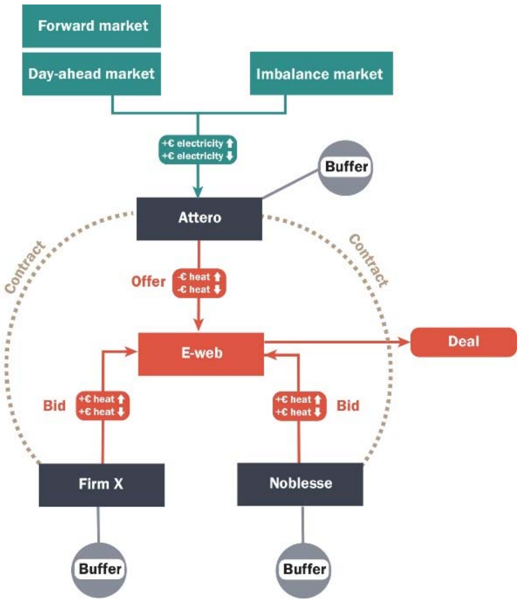

Figure 19. Business model concept with buffer

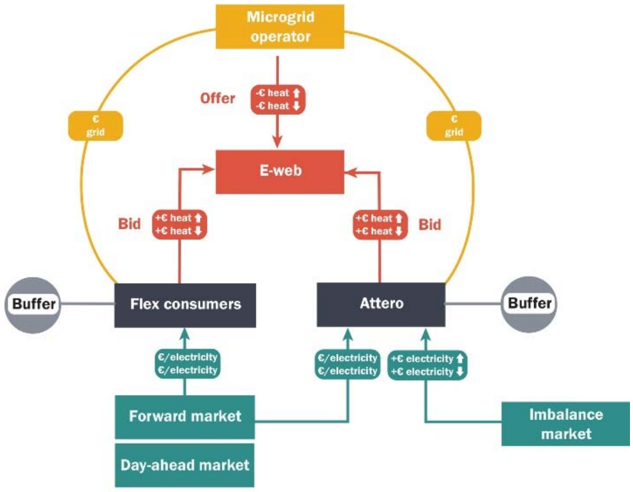

Figure 20. Business model concept with micro-electricity grid

Figure 21 depicts the concept that all the stakeholders agreed up on. This version of the business model concept is can be viewed as a variant of the business model concepts presented in figure 17 and figure 19. In this business case in addition to Noblesse we assume two additional fictive firms. One is a power to gas unit and the other is a district heating customer. Furthermore, the district heating customer owns and operates a heat buffer. Technical details of the heat consumers are described in section 0.

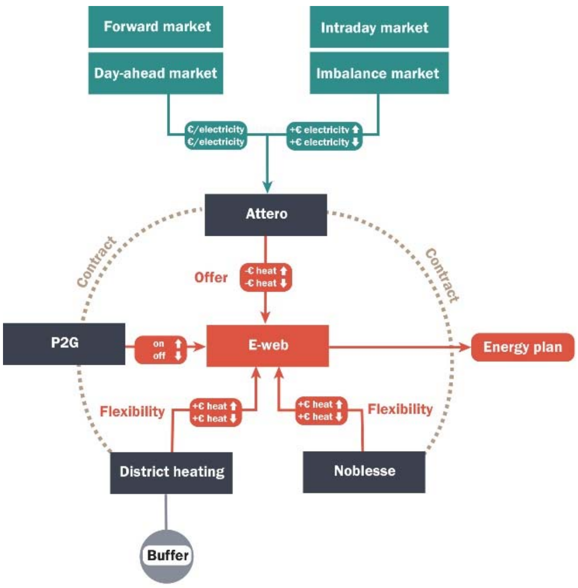

Figure 21. Final concept

6.3. Stakeholders

This section describes the different stakeholders and their goals for participating in this business ecosystem.

Attero: Attero is the central actor in this business ecosystem. They initiate and coordinate this business ecosystem. Attero's core business is to process waste. They burn the waste that cannot be further processed into higher value products. There is little or no flexibility in terms of the amount of waste that has to be burnt; however, they are flexible in the type of energy they can produce. Attero generates electricity from the steam produced in the boiler, but also has the possibility of extracting heat of different qualities at different heat extraction points in the steam cycle (see section 6.5).

Currently Attero supplies 18 MW_{th} high quality steam to Noblesse at approximately 175 degrees Celsius and 6,7 bar. However, Attero wants to explore the possibility of profiting from high prices on the electricity market (specifically the imbalance market) by operating flexibly in cooperation with the consumer(s) located at the ETP. The profits earned by exploiting the arbitrage opportunities will be shared with the firms offering the flexibility. By doing this Attero wants to attract more heat consumers to ETP Wijster. Attracting more heat consumers will lead to higher profitability for Attero. Furthermore, selling more heat directly also increases the energy efficiency of their core business i.e., waste processing. Therefore, Attero's goal in participating in this business model is profit maximisation and increasing the energy efficiency of their core business, which is expressed in the R1 value.

Flexible consumers (e.g. Noblesse): This stakeholder is defined as a role. Multiple companies located at ETP Wijster can take on the role of flexible consumer. The flexible consumers are connected to the heat network at the ETP wijster. They currently sign long term contracts with Attero for heat at a fixed price. The price is pegged with gas prices and is usually 25% lower than the average gas price. However, these flexible consumers can use the flexibility inherent to their industrial processes in order to consume more or less heat when it is most advantageous on the electricity markets. The main goal of the flexible consumers here is to minimise their energy costs.

Program responsible party (PRP): The PRP is supposed to submit E-programmes on behalf of its customers. TenneT then measures the actual amount of energy produced and consumed based on the E-programmes submitted (TenneT, 2014b). The PRPs are also allowed to carry out balancing activities within their portfolio. For example, if they notice that one of their consumers is producing or consuming more or less than stated in the e-programme they can source additional energy or sell additional energy to a third party in order to balance out their customers deviation from the e-programme. The PRP utilizes the flexibility offered by Attero in order to trade on the balancing market or use the flexibility to balance their internal portfolio. However, for this business model we have assumed that the PRP leverages the flexibility to trade on the balancing markets (active balancing through the PRP). Furthermore, the PRP accesses the flexibility offered by Attero via an aggregator.

Markets: Four markets energy markets are of importance to this business model namely the over the counter (OTC), day-ahead, Intraday (Nordpool), and Imbalance market. Attero along with the flexible consumers can capitalise on the trade opportunities that exist on the different market. To be able to leverage the arbitrage opportunities that exist on the imbalance market, Attero will need to closely collaborate with their PRP who can control their energy generation assets. The PRPs usually control the energy generation assets of their customers via an aggregator.

Table 5 Stakeholders, roles, and responsibilities

STAKEHOLDERS	**ROLES**	**RESPONSIBILITIES**
Attero	Energy producer	• Burn waste to produce high quality heat • Own and operate electricity/ heat generation assets • Supply heat to heat customers • Convert the remainder of the heat to electricity • Utilise the flexibility of the heat customers to maximise revenue on the electricity markets • Trade electricity on energy markets • Collaborate with PRP and external aggregator to maximise revenue • Facilitate the control of energy generation assets by external aggregators
Noblesse, District heating customers	Flexible consumer	• Utilise heat supplied by the energy producer for industrial processes • Offer flexibility to Attero via e-web • Consume heat based on the planned consumption and the deals made on the e-web
Attero	Internal Aggregator	• Setup and operate an internal trade platform (e-web) • Aggregates flexibility from all the prosumers and offers it to Attero • Control the flow of heat based on the planned heat consumption and trade executed on the e-web • Execute trades based on the price and quantity input provided by the prosumers • Meter the amount of heat supplied • Perform settlement activities based on the trades executed between Attero and the prosumers and the actual amount of steam consumed
PRP	External Aggregator	• Offer an trading platform where Attero can offer their flexibility and PRPs can purchase flexibility • Control the energy generation assets of Attero based on the trades executed
This role can be assigned to multiple stakeholders such as essent and eneco	Energy supplier	• Supplies and buys energy to and from Attero • Actively trades with Attero via markets • All the trades executed by attero on the markets and on the trade platform operated by the external aggregator have to be settled via Atteros energy supplier
APX, Nordpool, TenneT etc.	Energy Markets	• Provide and operate an energy trading platform
This role can be taken on by several actors	Program responsible party	• Active on the energy balancing market • Provides balancing services to the system operator • Purchases flexibility via aggregators • Compose e-programs on behalf of the prosumers and submit it to the system operator (TenneT) • Compose and submit T-programs to DSOs • Receive v-programs and ensure that the production, and consumption schedule adhere to the v-program • Inform the prosumers of the v-program • Setup and operate program management information service • Incase of deviations from the program pay fines to TenneT • Redistribute fines to the parties causing imbalance

TenneT	System operator	• Sets up and operates high voltage transmission system lines • Provides transportation services (approx 40.000 to 60.000 euros/MW grid capacity) grid capacity • Sets up and operates balancing markets • Check e-programmes • Request changes in e-programme if necessary • Send V-programmes(approved e-programmes) back to PRPs • Receive metering data from the DSOs and check if it matches with v-programmes and hand out fines if necessary
Enexis	Distribution system operator	• Setup and operate distribution system lines for gas and electricity • Receive T-programs from PRPs and forecast any possible congestions • Connect consumers and producers to their network • Collect metering data and make it available to the relevant energy retailers and the system operator

Aggregator: There are two types of aggregator roles defined in the business ecosystem namely the internal aggregator and the external aggregator. The internal aggregator is responsible for setting up and operating the internal trade platform that will be used by Attero and the prosumers on ETP wijster to trade flexibility. This role can be assigned to Attero or a third party. The external aggregator offers a trade platform to Attero who can place bids on the external aggregators platform. The external aggregator will then control the energy generation assets of Attero based on the trades executed on the platform.

Energy supplier: This role can be assigned to energy retailers (Essent, Eneco, etc.). All the purchases and sales of electricity to the markets has to happen through an energy retailer, for which the energy supply company is an indispensable role, but not a significantly different role than it currently has.

Distribution system operator (DSO): The DSO in the area of the ETP Wijster is Enexis. They provide the electricity transport infrastructure to Attero.

Table 5 provides an overview of the roles and responsibilities necessary to realise the designed business ecosystem. Furthermore, it also provides an overview of the stakeholders to whom the roles have been assigned.

6.4. Information service architecture

Figure 23 describes the information services operated by different stakeholders and the information exchange among them that are necessary for a viable business ecosystem. Core to the information service architecture is the existing of both an internal and external trade platform as Figure 22 shows in concept. The various information services operated by each stakeholder and the information exchanges among them will be described in detail in the following section.

Internal aggregator (Attero): The internal aggregator owns and operates three main information services namely the energy web (E-web), metering services, and clearing house/billing information services.

Internal trade platform (E-web): The internal trading platform aggregates the flexibility available at the ETP. It is an energy trading platform that facilitates the trade of flexibility. Flexible consumers can submit how much more or less steam they are willing to consume and at what price by submitting bids and at the same time it allows Attero to choose among the different offers. The offers are chosen on a cost based merit order up to the point Attero's capacity to trade is exhausted. Any bids that are not on the cost bids merit order will be disregarded. Additionally, it sends control signals to the steam controller that regulates the amount of steam based on the trades executed on E-Web. Furthermore, the E-web also sends information on the trades executed internally to the clearing house/billing information service. However, for the sake of simplicity we have not modelled the internal information flows between the clearing house/billing information services and the E-web.

Each firm has access to the trade platform to submit bids in a protected environment. Like the APX day-ahead market, the bid consists of the quantity of energy available in each PTU and the price per unit of energy. An important difference with the APX and a strong characteristic of this trade platform is that the trades executed are not based on a market clearing mechanism, but on bilateral trade. Each firm sets the price and quantity of their flexibility individually. The cconsumption schedules and the potential flexibility should be submitted two days in advance, with the option of offering additional flexibility up to 2 hours before consuming the steam.

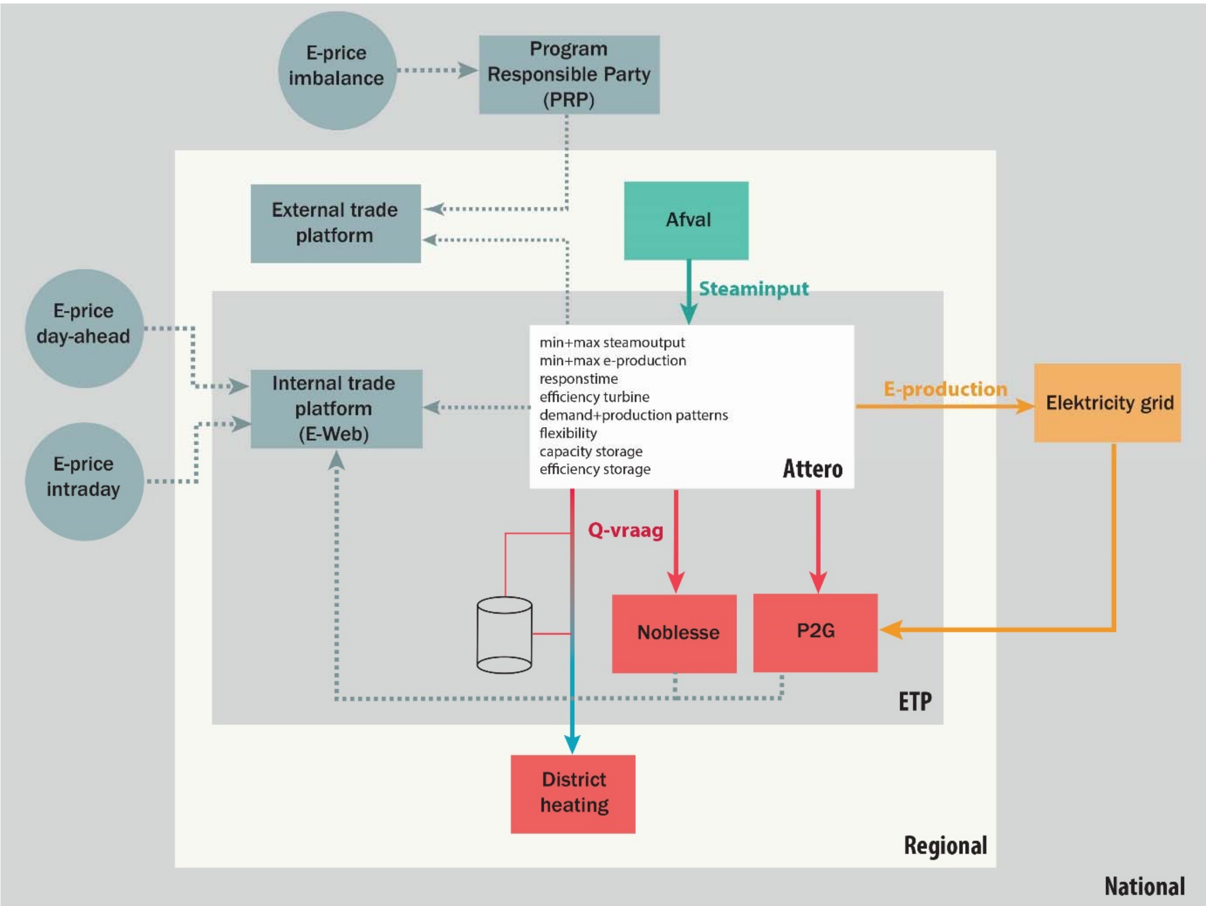

Figure 22 Business ecosystem with internal and external trade platform

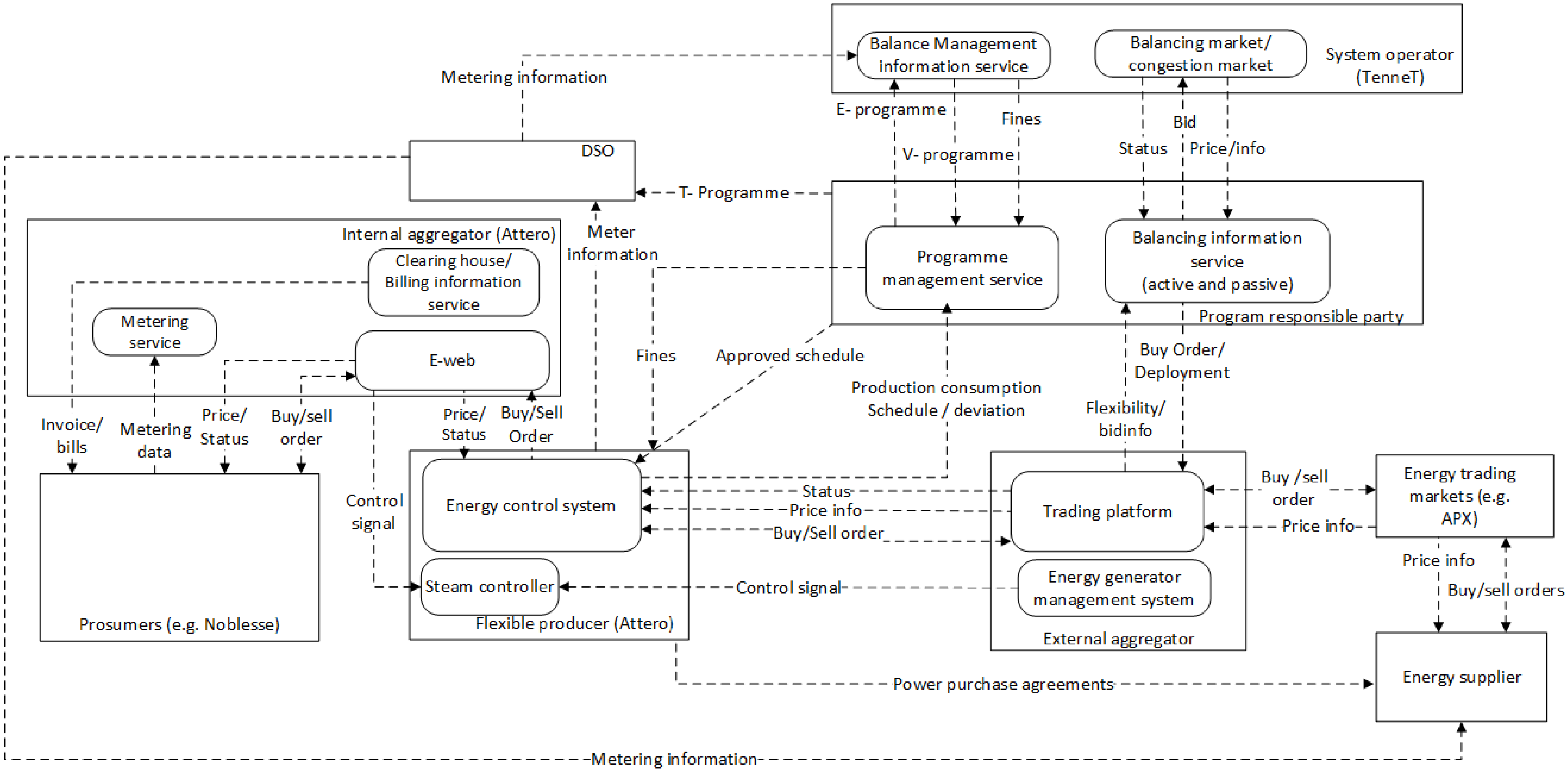

Figure 23. Information systems architecture for the ETP

The price of flexibility will be determined by the marginal costs of flexible operation. Here we make a distinction between industrial consumers and households. We assume that industrial consumers will set their own price, which will be based on the marginal costs of production and a profit margin. Households will not set their own prices, but the price of flexibility for the district heating system is based on the marginal costs of using the heat buffer.
When the additional revenue gained from the electricity markets is higher than the marginal costs of flexible operation, the trade is executed. Figure 24 shows a possible interface for an internal trade platform. Firms indicate their flexibility for each PTU and directly see the results of the bidding process.

The bidding process consists of the following steps:

1. Actual electricity prices are loaded automatically
2. Each firm submits planned production
3. Each firm submits capacity for flexibility
4. Each firm submits price for flexibility
5. Preview result
6. Finalize bid
7. Approval of the counterparty
8. Control signal

The heat-consuming firms will have to make costs to shift heat their consumption, and therefore want to receive sufficient compensation. There are several ways of sharing the profits earned by this process: 1) Firms offer their flexibility at marginal cost, and the profits earned by the arbitrage opportunity are shared equally between the company offering the flexibility and Attero, and 2) Firms offer flexibility at any desired price, including marginal cost and a profit margin. The last option is particularly suitable in a competitive setting where the highest bid is selected. In the context of the ETP there is no such competitive setting with sufficient firms to have proper market conditions, so option 2 is preferred.

Metering service: The metering service collects the consumption data from the power plant and the flexible consumers and relays that information to clearing house and billing information service.

Clearing house/ billing information service: The clearing house and the billing information service in essence are two separate information services. However, for the sake of simplicity we have combined the two information services here. The clearing house information service automates the process of settling the balances. This involves accounting for several variables and reconciling them with each other such as how much was the planned consumption, the amount of flexibility offered by prosumers, the amount of flexibility purchased by Attero and what price, deviation from the planned consumption, revenue sharing etc. The billing service then leverages this information to send correct and timely bills to the prosumers.

Flexible producer (Attero): The flexible producer owns and operates the energy control system and steam controller.

Energy control system: The energy control system monitors the prices on the trading platform of the external aggregator and on the E-web. It then executes profitable trades on both the platforms.

Interface trade platform

Date	7-1-2015
Markt	APX

Treshold	12	Average APX	50

PTU	Electricity price	Noblesse			DH network			Power to gas (hydrogen)			Result Noblesse	Result DH network	Result P2G	Additional revenu
	C (€/MWh)	Qplanned (MW)	Qvar (MW)	C (€/MWh)	Qplanned (MW	Qvar (MW)	C (€/MWh)	Qplanned (MW	Qvar (MW)	C (€/MWh)				
1	36,11	18	3	10	42	42	10	0	2	49	up	DH	off	0,00
2	34,31	18	3	10	42	42	10	0	2	49	up	DH	off	0,00
3	32,55	18	3	10	38	38	10	0	2	49	up	DH	off	0,00
4	32,08	18	3	10	38	38	10	0	2	49	up	DH	off	0,00
5	29,48	18	-3	25	39	39	10	0	2	49	0	DH	off	0,00
6	34,31	18	-3	25	44	44	10	0	2	49	0	DH	off	0,00
7	35,78	18	-3	25	46	46	10	0	2	49	0	DH	off	0,00
8	45,98	18	-3	10	46	46	10	0	2	49	down	DH	off	36,78
9	47,91	18	-3	10	46	46	10	0	2	49	down	storage	off	313,81
10	48,91	18	-3	10	44	44	10	0	2	49	down	storage	off	308,13
11	50	18	3	15	43	43	10	0	2	49	0	storage	off	268,75
12	51,22	18	3	15	43	43	10	0	2	49	0	storage	on	275,31
13	50,15	18	3	20	43	43	10	0	2	49	0	storage	on	269,56
14	51,46	18	3	20	43	43	10	0	2	49	0	storage	on	276,60
15	50,88	18	3	20	44	44	10	0	2	49	0	storage	on	279,84
16	48	18	3	20	44	44	10	0	2	49	0	storage	off	264,00
17	47,14	18	0	0	44	44	10	0	2	49	0	storage	off	259,27
18	51,07	18	0	0	45	45	10	0	2	49	0	storage	on	287,27
19	47,42	18	3	10	46	46	10	0	2	49	up	storage	off	272,67
20	44,83	18	3	10	46	46	10	0	2	49	up	storage	off	257,77
21	39,1	18	3	10	44	44	10	0	2	49	up	storage	off	215,05
22	42	18	3	10	43	43	10	0	2	49	up	storage	off	225,75
23	37,92	18	0	20	43	43	10	0	2	49	0	storage	off	203,82
24	33,51	18	0	20	43	43	10	0	2	49	0	DH	off	0,00

Figure 24. Interface of the internal trade platform, including Noblesse, a district heating network and a P2G as heat consumers.

Steam controller: The steam controller receives control signals from the E-web (for the APX optimization and Intraday trade) as well as the energy generator management system from the external aggregator (for the Imbalance trade). It regulates the flow of the steam led to the turbine and the different heat extraction points. The steam controller translates the automatic control signal from the PRP into actual ramping up- and down of the turbine.

Flexible consumers (e.g. Noblesse): The prosumers log in to e-web information service and register their flexibility. The prosumers may own and operate their energy management system. However, it is beyond the scope of this report to model the energy management systems of the prosumers that they use for their internal purposes. They also receive information / reports on the status of their orders from e-web. Additionally, they also get bills and invoices from the internal aggregator.

Furthermore, they meters installed on the prosumers premise also transmit metering data to the internal aggregator.

External Aggregator: the external aggregator owns and operates two platforms namely the trading platform and the energy generator management system.

External trading platform: The trading platform on the one hand aggregates several markets such as day-ahead, intraday and the imbalance market, and on the other hand, it aggregates flexible producers and consumers. The flexible producer can trade energy on the day-ahead as well as intraday and offer their flexibility to the PRP for a minimum price.

As explained in section 3.7, imbalance trading cannot take place without interference of a PRP unless there is a direct contract for active balancing with TenneT. The aggregators provide access to the imbalance market via a PRP. We have chosen passive balancing through the PRP as strategy for the imbalance market. To facilitate trade on the imbalance market, an external trade platform exists through which the flexible producer can place bids and take offers from the PRP. The PRP executes the trades on the trading platform. After the trades are executed, appropriate information is made available to the energy producer management system.

Similar services are developed in the market, for example AgroenEnergys' FLexPower products (AgroEnergy, 2016). These products enable the greenhouse businesses offer their flexibility to the PRP, for example by indicating the times when the CHP can be up- or downregulated compared to their APX position. AgroEnergy in this case, sends an automatic control signal when the flexibility is being utilized.

Energy producer management system: The energy producer management system sends control signals to the steam controller based on the trades executed on the trade platform.

Program responsible party (PRP): The program responsible party owns and operates the two important information services namely the balancing information service and programme management service.

Balancing information service: As the strategy of the business ecosystem for the ETP is passive balancing through the PRP, the PRP will constantly monitor the imbalance market prices and act upon profitable imbalance prices by sending a control signal to the power plant. The PRP will then allocate revenues to Attero based on revenue sharing agreements.

Programme management service: The programme management service mainly collects production and consumption schedules from producers and consumers. The information system will then process all of these schedules in to e-programmes and submit it to the system operator. It will then receive approved v-programmes from the system operator and relay back the approved production and consumption schedules to the producers and consumers. Furthermore, it will also allocate the fines to appropriate stakeholders.

The PRP also submits a T-programme to the DSO.

System operator (TenneT): In context of this business model the system operator owns and operates two relevant information service namely the balancing market and the balance management system.

Balance management information service: The balance management information service collects all the e-programmes and checks them for consistency, and it then relays the approved programme known as the v-programs back to the PRPs. In addition, the system also cross verifies the actual consumption against the submitted programmes, and it calculates the fines accordingly and communicates it back to the PRPs.

Balancing market: This platform receives the bids from the market parties, and publishes the imbalance price in real-time. Furthermore, it also informs parties who have been actively selected by TenneT to provide electricity to balance the grid. The parties not selected by TenneT to provide electricity to balance the grid can still choose be passively balance the grid at their own risk.

There are several other information services owned and operated by several stakeholders in this ecosystem. However, for the sake of simplicity we have not modelled those information services. Nevertheless, we have modelled the relevant information exchanges among the different stakeholders. The rest of this section focuses on the afore-mentioned information exchanges. The DSO receives the meter data from the flexible producer. This is mainly read from a meter installed on the premise of the flexible energy producer. The DSO stores this information in a CAR database which is then made available to the TSO and the energy supplier. The energy supplier signs power purchase agreements with the flexible producer. Furthermore the trading platform of the external aggregator relays all the buy and sell orders to the markets and price information to the flexible producer. The energy supplier also trades on the energy markets that requires the exchange of information on buy and sell orders and price.

6.5. Technical architecture

6.5.1. Heat extraction

In most cogeneration plants that are connected to a district heating system, the heat that feeds the district heating system is extracted from the condenser. Here, there are three other heat extraction points that are used:

1. High pressure steam extracted right after the boiler (1). The temperature and pressure are brought down from 400 ^{0}C/40 bar to 175 ^{0}C/6,7 bar by leading it through a pressure reducer.
2. Mid pressure steam extracted before the turbine and led through a backpressure turbine (2)
3. Low pressure steam extracted from the turbine (3)

The different options for extracting steam from the plant gives potential for supplying a variety of third parties with heat. Currently, Noblesse, a protein manufacturer, is the only third party located at the ETP that receives heat from the plant. Noblesse receives steam from 175 ^{0}C and 6,7 bar from the high pressure and mid pressure steam extraction points. The steam is transported through an above-ground pipeline. The return flow is fed in the system at the feedwater preheater. Low pressure steam is extracted for the water purification and the bio-digester that are located at the facility.

Next to these existing heat customers we assume two additional uses of the heat: a district heating network using low-temperature heat (90 ^{0}C) and a Power-to-Gas (P2G) facility that produces hydrogen from electricity.

<u>District heating system</u>

Low pressure steam is extracted from the turbine and compensated in a heat exchanger and transported as hot water of about 90 ^{0}C to the consumers. We assume the district heating to be connected to a buffer as source of flexibility in the system. The return flow is fed into a stratification tank (buffer).

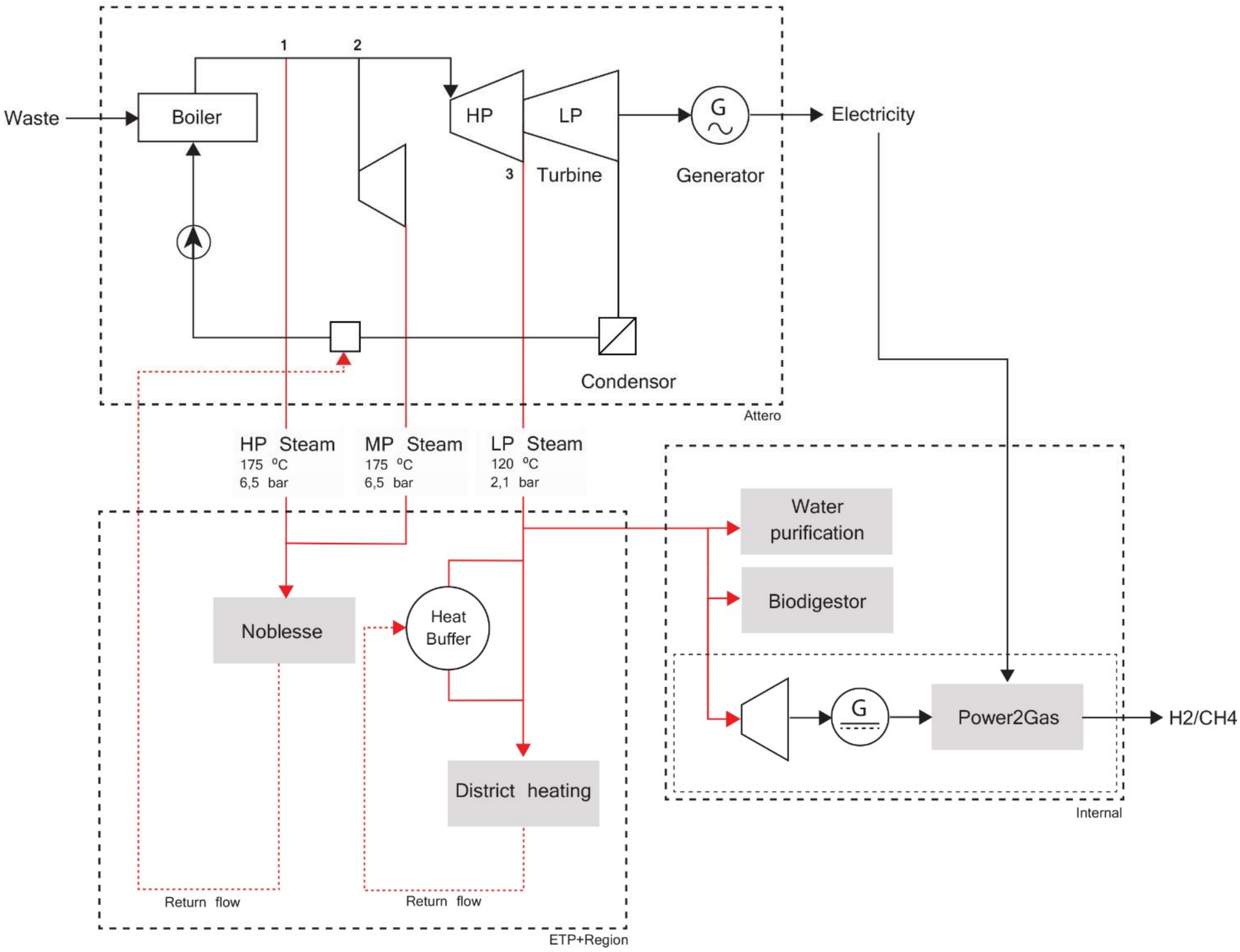

Figure 1. Technical architecture

P2G

One option is to use low pressure steam (120 ^{o}C) to produce electricity with a separate turbine outside of the R1 boundary. The advantage of this set-up is that the R1 value increases as the P2G facility is technically fed with heat from the plant and not with electricity. In fact, the P2G facility is considered as a heat customer. In both cases, an electrolyzer uses the electricity to produce hydrogen. In a final step the hydrogen can be converted to methane through a methanation process and fed into the gas grid. Using excess electricity from solar and wind can contribute to grid balancing in the future by storing electricity, which cannot be stored for longer time, in the gas grid, where it can be stored for days to months.

6.5.2 Heat profiles

For the flexible business model to function, multiple heat consumers need to be connected to the plant. The heat profiles (how much heat the consumers needs at what time) need to match the heat that is available at the plant. The plant with a capacity of 54 MW_e (200 MW_{th}) has the potential to supply heat to multiple consumers. Even with a district heating system and P2G facility the maximum heat extraction is far from being reached. Understanding the heat consumption patterns is important to determine the available flexibility at the different consumers. We categorize different consumer profiles:

- Day consumers: The prosumers has a consumption pattern that is repeated on a daily basis.
- Week consumers: The prosumers has a weekly consumption pattern that is similar. Noblesse is a company that fits the week prosumers profile they have contracted x amount of heat annually. On an average they consume 18 MW steam per hour. They usually don't consume any heat on weekends (Sunday-Monday morning) except for some exceptional weekends. We assume their industrial process allows them to consume 40-50 percent more heat than they have contracted, which allows some flexibility (Kwak, M, 2016. Pers.comm.).
- Seasonal consumers: The prosumers have a seasonal demand for heat, for example district heating customers. The consumption pattern of the district heating customers is relatively in elastic. They demand low quality heat for space heating purposes when it is cold. Hence, they mainly consume heat during early autumn, winter, and early spring. For the sake of this business model we have assumed that a district heating networking consuming on an average x amount per month is connected to Atteros heat network.
- Base load consumers: The prosumers has a fairly constant and relatively inflexible demand for heat
- Temperature consumers: The prosumers consumption is very sensitive to the temperature. These customers may demand different qualities of heat at different periods depending on the different stages of industrial processes (for e.g., breweries).

Bio-digester and water purification

The bio-digester only consumes heat during the coldest months. The water purification consumes heat throughout the year, but follows a seasonal pattern. These are both *seasonal customers*. The heat consumed is only a low share of the total capacity of the plant.

Noblesse

Noblesse has a *weakly pattern*. It is shut down during the weekend and started up again on Mondays. On week days the plant runs during day and night time and has a more or less consistent heat load (ca. 18 MW_{th}). There are days during the operation that there are larges swings in the heat consumption. We have no information on the production process of Noblesse so we cannot explain these swings.

District heating system

The district heating system supplies the heat demand of households. The households are both daily and seasonal consumers. During winter heat demand is significantly higher than during summer because of the higher need for space heating. These fluctuations can be leveled out by a heat buffer. In combination with a heat buffer the business ecosystem as a whole can obtain flexibility. At hours when the electricity price is high, all the steam produced is converted to electricity and the heat from the district heating is extracted from the buffer. During hours with a low electricity price, it is more profitable to use part of the steam to charge the buffer.

P2G

The P2G facility does not follow a consumption pattern and can be operated whenever the electricity price is low. In order to be profitable there is a minimum of hours that the plant must operate. Our analysis is section 7.3 shows the profitability of a P2G application at the ETP.

6.5.3 Technical limitations

Minimum and maximum heat extraction

The heat delivered to third parties is bounded by the technical boundaries of the plant:

1) There is a minimum mass flow through the turbine that must be maintained;
2) The sizes of the drain valves determine the maximum mass flow at the extraction points;
3) The R1 value must not be lowered by flexible operation
4) The pressure at the condenser (explained in more detail below)

Condenser

By flexible operation of the plant, the mass flow through the turbine can vary from hour to hour. The pressure at the turbine outlet will increase accordingly. The condenser is sensitive to changes is pressure. The pressure at the turbine outlet may have a certain value according to the design criteria. However, the real value must be measured in practice.

Ramp up and down rate

As a result of a flexible operation, the power plant needs to change the mass flow through the turbine regularly. The load that can be added or taken from the turbine per unit of time without overstressing the turbine is called the ramp up and ramp down rate. There are probably values known from the manufacturer. These theoretical values need to be validated by measurements from practical tests. As long as the flexibility only involves a small change (ca. 5 MW), the turbine will probably only needs minutes to change the turbine load.

Start-up time of the P2G facility

The P2G facility will be used as a flexible energy conversion system. To extent to which it can be used in a flexible manner largely depends on the start-up time. A demonstration project of a P2G facility in

Rozenburg has identified start-up times of the electrolysis and methanation processes (Vlap, Van der Steen & Grond, 2015). The electrolyzer can be turned on in several minutes. The methanation process takes significantly more time. The reactors needs almost 30 min to warm up. After the reactors are sufficiently warmed up, the carbon dioxide is added to start the methanation process. This takes another 10 min. For flexibility this means that a start-up time of about 40 min requires a more or less planned approach. It would be possible to incorporate the P2G production in the day-ahead trading program. The flexibility may not be sufficient to trade on the volatile imbalance market by lowering the electricity sold to the grid (downward regulating).

<u>Measurability of change in electricity</u>

With only one firm currently located at the ETP Wijster, there is only limited flexibility available at the consumer side. We have assumed Noblesse to have a flexibility of 3 MW_{th}, which corresponds to a change in electricity output of approximately 0,8 MW_e. Such small changes in electricity output are hardly measurable, especially since the electricity production has a normal swing of a few MW. Trading flexibility on the electricity markets is only possible when the effects are measurable. If that involves a change in electricity output of 5 MW_e, a flexibility of about 18 MW_{th} is needed from the consumers.

6. Validation of the business model

7.1. Model design

The basic idea of the flexible business model is that the ratio of heat and electricity can be changed in order to optimize the heat and electricity sold to maximize profit given the constraints of Attero's capacity to produce heat and electricity, and the flexibility of the consumers (time shift and quantity shift). The techno-economic model matches the electricity prices on different markets with the demand profiles in such a way that heat and electricity are produced in the most profitable way. The aim of the model is to calculate the potential revenue that can be gained from operating in a flexible way. In reality, the trading platform is not an optimization mechanism, but firms determine if the trade is executed and at what price. The model uses historic data, including the 2015 day ahead, intraday, and imbalance prices, and the production- and demand patterns. Using this data, the model calculates the potential profit that can be made by capitalizing on the arbitrage opportunities that exist on the above-mentioned markets by leveraging flexibility.

Flexibility variables:
The model includes different flexibility variables:

For industrial firms (Noblesse):

- Production shift: the quantity of heat that can be changed in flexible operation
- Time shift: the amount of consecutive hours that the firm can consume more or less heat

We assume that their industrial process allows them to postpone or prepone the steam consumption by 3MW up to a maximum of 2 hours. For example, if they have planned a consumption of 18 MWh of steam at 12:00 they can postpone 3MWh of that consumption up to 14:00. Hence, at 12:00 they can be supplied with 15MWh of steam instead of 18MWh of steam and at 14:00 Noblesse will need to be supplied with 21MWh of steam instead of 18MWh. Similarly, they can be supplied with a maximum of 21 MWh of steam after 10:00 in order to supply them with 15MWh of steam at 12:00.

For district heating:

- Buffer: heat can be stored and consumed again within a time frame of 24 hours. This variant is chosen to make most use of flexible operation.
- Seasonal storage: the full capacity of heat delivery is used continuously. The heat load is levelled out over the year: the surplus of summertime is stored and used for the shortage in wintertime. This variant is chosen to sell the maximum amount of heat.

For P2G:

- On/off: hydrogen and methane production can be switched on when the electricity price is beneficial.

Optimization
The model 'matches' the electricity prices with the flexibility available. We do this by simulating each day of the year in one-hour time blocks and generating an energy plan which focuses on meeting the energy demand of the heat consumers while simultaneously optimizing the profits obtained from electricity sales on the various electricity markets. The model is designed to optimize the financial

aspects of the energy production within a 24 hour period. Each day is analyzed independently, with some possible carry-over effects from the previous day.

The relation between heat extraction and electricity production is modelled in a thermodynamic model (steam turbine model). The steam turbine model calculates the electricity to the grid resulting from increases and decreases in the steam demand.

First, we optimize the electricity and steam production for the day-ahead market, which we can plan for each hour of the day, for 24 hours. We allow steam production (and thereby electricity production) to shift up or down by the amount defined by the *Production Shift* variable. We also set a limit to the number of consecutive hours (i.e. time block) that the production can be increased or decreased. The total quantity of heat delivered must not change within a given time block (i.e. the time period defined by the *Time Shift* variable). For a time shift of 3 hours, this means that if the production is increased for 3 consecutive hours, the next 3 hours should be used to lower the production so the total daily steam demand is met. At the end of the day, the total daily heat demand of the heat customer stays the same, but it is supplied with a different profile. In this way, we plan to produce as much electricity as possible while electricity prices are high, and produce steam to compensate for this while electricity prices are low. The result of this optimization process is an 'optimized energy plan'.

Then, the energy plan is further optimized for the Intraday and Imbalance markets. For those markets we cannot plan ahead for a 24 hour period, so we choose a 'real time' approach: we set a threshold price that defines when it is profitable to trade electricity. If the price is higher than this threshold, we choose to change the APX optimized energy plan to the maximum electricity production possible at that time, and if the prices are lower than the threshold price no changes are made to the optimized energy plan. Any shortcomings in total daily steam production as a result of these shifts are made up in the earliest hours of the following day, when the electricity prices are the lowest. Any surpluses in steam production as result of down-regulating on the imbalance market are not made up for as we allow a higher steam production as long as the revenue for the heat customer is increased. In this way, steam demand is always met, though it is supplied with a different profile.

The model is further described in detail in Appendix A: Manual APX Price Matcher (techno-economic model).

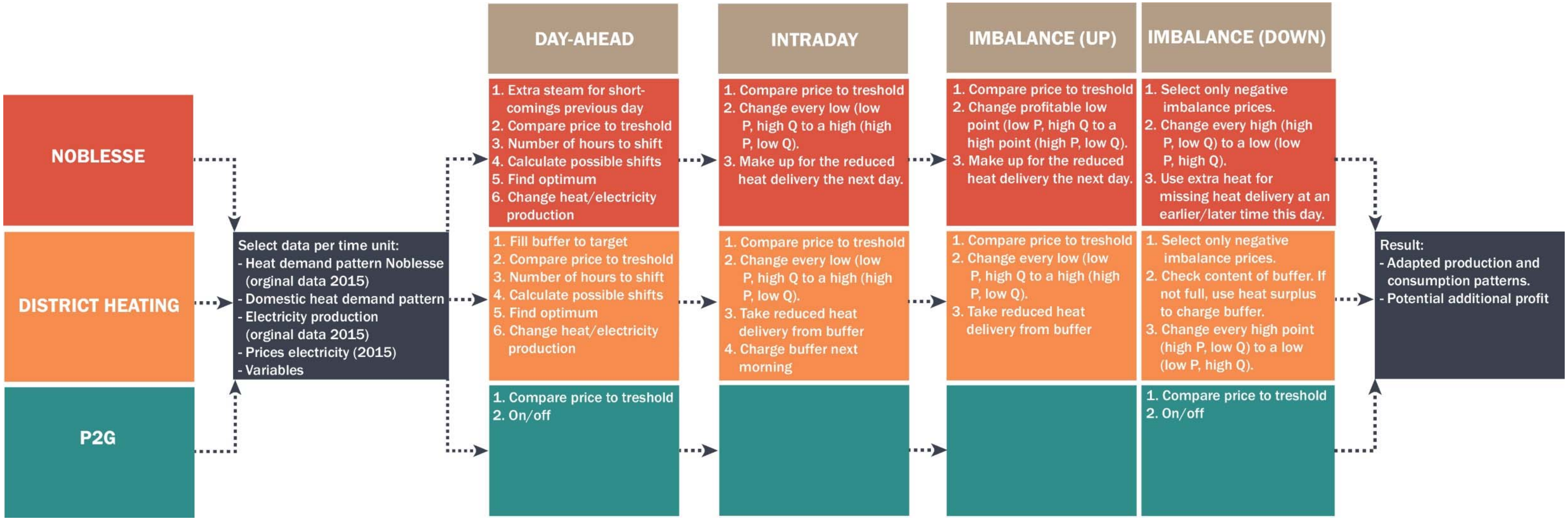

Figure 25 Schematic representation of the techno-economical model (APX Price Matcher)

7.2. Underlying assumptions

7.2.1. Markets

Optimization of electricity sales

As outlined in chapter 0, electricity producers have the opportunity to sell their electricity on different markets and in that manner optimize the electricity sales. Depending on the prices on different markets, a producer will decide to sell shares of the volume on the forward market, day-ahead markets and by bilateral trade. We assume a ratio of 80 percent forward market and 20 percent day-ahead market (Sanders, M., 2016, Pers. Comm., 21 March). Overall, electricity on the Dutch wholesale market is traded for 20 percent in bilateral contracts, for 60 percent on the Over-the-counter market and for 20 percent on the APX day-ahead market (ACM, 2012).

Imbalance market

We assume passive balancing through the PRP. In the current situation it is not possible to trade on the imbalance market without interference of the PRP. Neither do we know the regulating status (delta) and prices 15 minutes in advances. Passive balancing through the PRP means that Attero places bids for flexible operation (up to about 1 hour in advance) which may or may not be engaged by the PRP. This balancing strategy can only function under two basic conditions:

1. There is a cooperation contract with the PRP. In this contract agreements are made concerning a guaranteed price for providing balancing power and profit-sharing;
2. There is a control mechanism (combination of hardware and software) through which the PRP can send a control signal to the power plant.

Price risk

In the model, we calculate the most optimal trade. In reality, trade gates close hours or days in advance. This results in price risk. For example, forward price may appear to be higher than day-ahead prices. Imbalance bids may not be engaged. The actual trade taking place will therefore be lower than the results the model gives because the model gives all possible trades and does include a forecast of how frequent transactions could take place. We account for this in our business case calculations by lowering the revenues that can be obtained from these markets.

7.2.2. Technology

Production shifts

The viability of the business model is dependent the degree of flexibility of the heat customers. As we don't know the production process of Noblesse or any other customer, it might very well be the case much less 'shifts' in the planned production are possible. The actual revenue highly depends on the flexibility in the production process of Noblesse (or any other connected firms).

Storage in the district heating scenario

Modelling of storage is a complex matter. As the aim of this study is not to understand the dynamics of storage, we have made some simple assumptions for the storage. We dimension the buffer large enough for a 24hours optimization and for a seasonal optimization. We assume the buffer to be half full continuously.

By buffering and transporting heat losses occur. Although heat losses are dependent on a number of variables, we assume a fixed transportation loss (10 per cent) over the district heating network and fixed losses (10 per cent) in the buffer.

7.2.3. Financial

Heat price

Noblesse pays a fixed heat price. We assume this to be equal to the average annual day-ahead price minus a discount of 25 percent.

The district heating price is equal to the maximum heat tariff according to the heat law, which is € 22,64 (ACM, 2016) minus a discount of 10 percent. We assume a discount because in our business model all parties will profit from the flexibility in the system. Although we didn't include this in the model, it is possible to let district heating consumers profit from the flexibility by applying dynamic pricing.

Electricity prices

We assumed prices over 2015. The model can also be used to simulate scenario's for other years by loading different data sets.

Forward prices are not publicly available. We assume the APX day-ahead price plus €15/MWh (Sanders, M., 2016, Pers. Comm., 21 March). In 2015 prices have been higher on the forward market than on the day-ahead which makes it more attractive to sell all the electricity on the forward market.

7.3. Results

We have modelled three different scenarios:

1. Noblesse + water purification + bio-digester
2. District heating network with a buffer
3. Power-to-gas

In this section we will present the results, the potential revenue, for each of those scenario's.

7.3.1. Yearly revenue

Noblesse scenario and district heating scenario

Table 6 shows the results of the model simulations for the Noblesse and district heating scenario. It shows the annual revenue increase on the electricity production. With a variable production (production shift) of 3 MW_{th}, (0,8 MW_e) an additional revenue of around 9 per cent can be achieved.

Although the scenario with the seasonal storage gives a higher absolute profit, the scenario with the daily storage is the most attractive scenario for the ETP Wijster as it is difficult to reach a number of connections as high as 50.000 in the surroundings of the ETP and because the daily storage offers the best possibilities for flexible operation.

Note that these results only apply to potential revenue, not profit. In chapter 8 will present a business case, taking also costs into consideration.

Table 6 Results APX Price Matcher per scenario

Scenario	Production Shift	Time Shift	Threshold	District Heating	Annual Revenue Increase (%)	Annual Revenue Increase (absolute - no DH sales)	Base Case	DH Sales (@ 73.35 euros / MWh)	Electricity "Losses" (euros)	Number of ramp ups
1	3	2	37.5 / 87.5	N/A	0,99%	€ 158.251	€ 16.000.000			2.511
2	3	4	37.5 / 87.6	N/A	0,98%	€ 156.922	€ 16.000.000			2.297
3	3	6	37.5 / 87.7	N/A	0,97%	€ 154.729	€ 16.000.000			1.562
4	3	12	37.5 / 87.8	N/A	0,97%	€ 154.413	€ 16.000.000			1.617
5	5	2	37.5 / 87.9	N/A	1,66%	€ 265.353	€ 16.000.000			2.511
6	9	2	37.5 / 87.10	N/A	2,95%	€ 471.826	€ 16.000.000			2.515
7	3	2	37.5 / 150	N/A	0,85%	€ 135.471	€ 16.000.000			2.269
8	3	2	33.5 / 87.5	N/A	1,02%	€ 162.926	€ 16.000.000			2.698
9	3	2	87,5	Daily Storage (16,000 houses)	1,82%	€ 444.879	€ 24.427.690	€ 11.506.591	€ 2.907.029	3.109
10	3	2	87,5	Seasonal Storage (40,000 houses)	0,40%	€ 159.769	€ 40.013.284	€ 27.759.349	€ 3.746.065	2.511

P2G scenario

The model for the P2G is a separate model and works slightly different. The P2G facility can be considered as a customer, just like Noblesse and district heating customers, but the production is not limited to consumer needs. The only condition for when to the flexibility of the P2G facility is the profit. There is an optimum amount of operational hours to make a positive business case. To make a profit, the P2G plant needs to run at the lowest possible energy cost. When the hourly APX day-ahead price is below a certain threshold or the Imbalance price is negative, the plant is turned on. The P2G business case model was used to calculate the optimum threshold price (which determines the number of operational hours) and sale price to get a positive business case (Net Present Value = 0). The results of this analysis can be viewed in Table 7.

Table 7. Results business case analysis P2G

Scenario	Treshold Imbalance (€/m3)	Treshold APX (€/m3)	Sale price (€/m3)	Market value (€/m3)
Hydrogen – heat	0	15,98	5,99	5 (estimate)
Hydrogen – electricity	0	19,95	4,81	5 (estimate)
Methane – heat	0	5,50	28,59	0,6
Methane - electricity	0	7,27	26,76	0,6

Both hydrogen scenarios seem to give a positive business case. The calculated (optimum) sale price is around the estimated market value. However, the hydrogen needs to be transported or processed in order to make it available for potential clients. Some possibilities are: storing the hydrogen in vessels to make it available for road transport, transport the hydrogen to clients at the ETP through a gas infrastructure or convert the hydrogen back to electricity. With all these options there are additional costs. Individual uses need to be studied further, but it is likely that the sale price will exceed the market value in any case.

The calculated optimal sale price of methane is far above the market value of methane. The direct use of electricity is somewhat more profitable than local electricity production with low-quality heat, but with a sale price of only € 0,60 (biogas price), the business case will not become positive.

7.3.2. Detailed results per day

As described in section 7.1, each day is analyzed individually. To get the yearly results, we compile the results from 365 days. This section describes in more detail how one day is calculated. We do this for a random day, June 3rd 2015, for scenario 2.

For the Noblesse scenario

First, the model optimizes for the APX day-ahead. We use a threshold price to determine for which hours it is worth to optimize. The threshold price is the steam sale price plus a margin of 25 percent[4]. If the prices exceed this point, it is more profitable for Attero to make electricity than heat so the electricity production is maximized. The model calculates the optimal energy plan (production of steam and electricity) over all the hours that the APX day-ahead price is above the threshold. This means that the steam production can be in- or decreased by the value of the production shifts (which is an input variable) at those hours.

Figure 26 shows the original steam production and the shifts that are made in the optimized energy plan, for a quantity shift of 3 MW and a time shift of 4 hours.

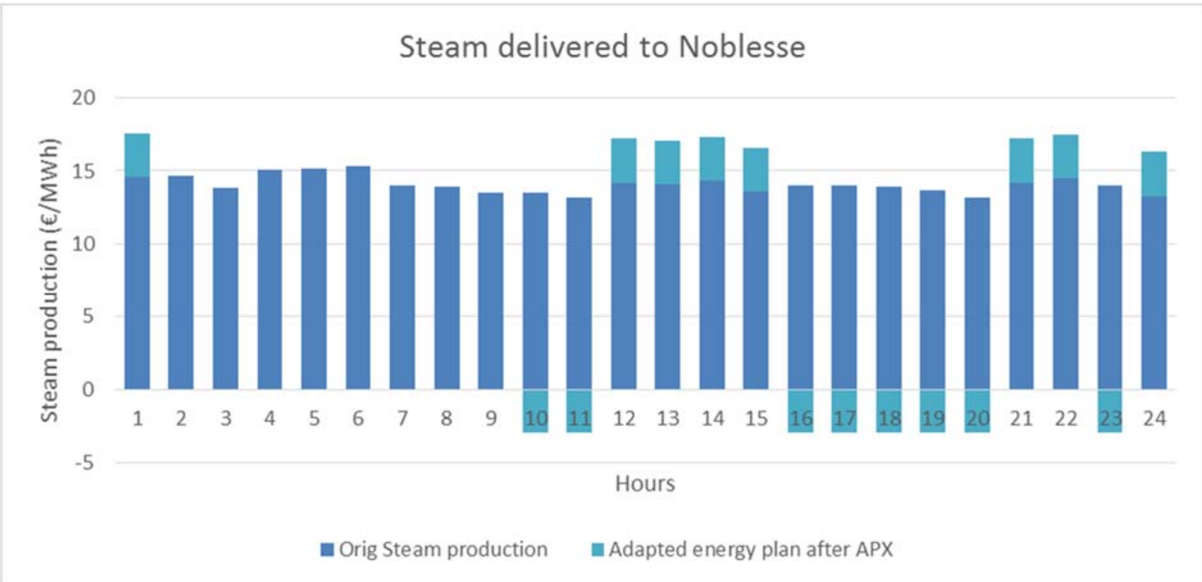

Figure 26 Steam delivered to Noblesse-APX optimized

Then, the model optimizes further for the Intraday market. For the Intraday there is also a threshold. The threshold is the APX day-ahead price plus the marginal costs of flexibility, for which we arbitrarily assume a value of 50 €/MWh. The marginal costs of flexibility is the cost of the waste incineration plant and the heat consumer (Noblesse) to ramp down the steam production in favor of the

[4] This margin is based on the financial advantage of producing steam over electricity (such as transportation costs, taxes and R1 value)

electricity production. The heat consumer needs to adapt the production process: at this hour it receives less heat (equal to the value chosen for the production shift) and the reduced quantity of steam will be delivered the next day instead. There will be a cost of shifting the steam consumption, which is the marginal cost of flexible operation. When the Intraday price exceeds the chosen threshold, it is profitable to sell more electricity. This is only possible when at this hour the steam production is equal to the original planned production or increased by the production shift according to the APX optimized energy plan, otherwise the plant cannot ramp up. Figure 27 shows the number of trades taken place on the Intraday market on June 3rd 2015.

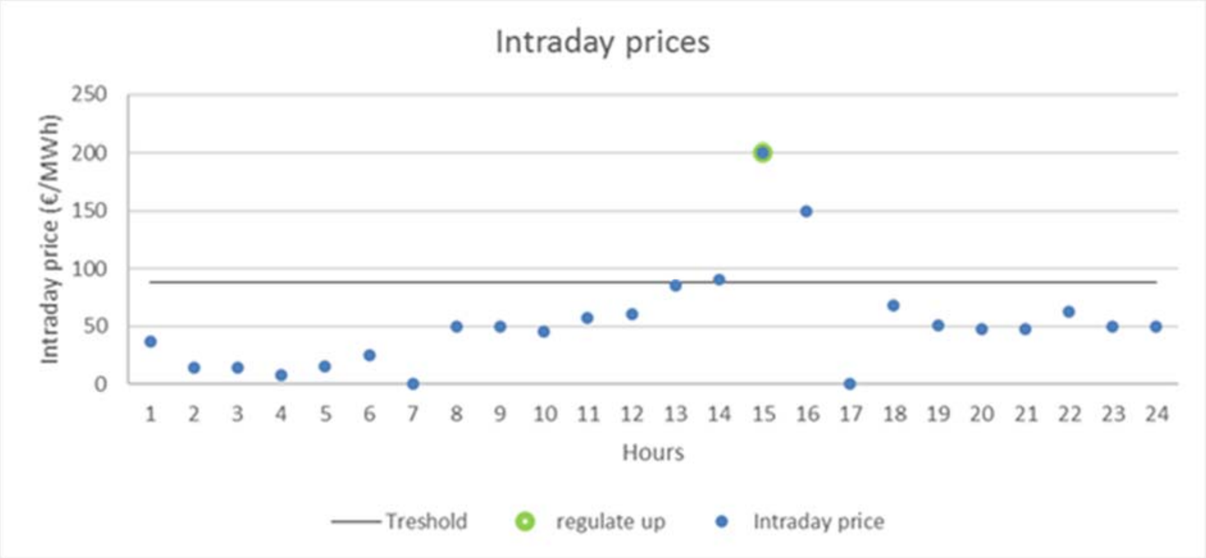

Figure 27 Intraday prices and trades

Figure 28 Imbalance prices and trade

After the Intraday optimization, the model optimizes further for the Imbalance market. For upregulating the mechanism is the same as for the Intraday market. For downregulating it is slightly different: we also use a threshold, which is 0 €/MWh (selecting negative prices only), but we do not make up for it the next day. In this case, the total daily steam is increased, but it is still profitable for Noblesse as they receive a compensation while not paying for the extra steam consumed. Figure 28 shows the number of trades taken place on the imbalance market on June 3rd 2015.

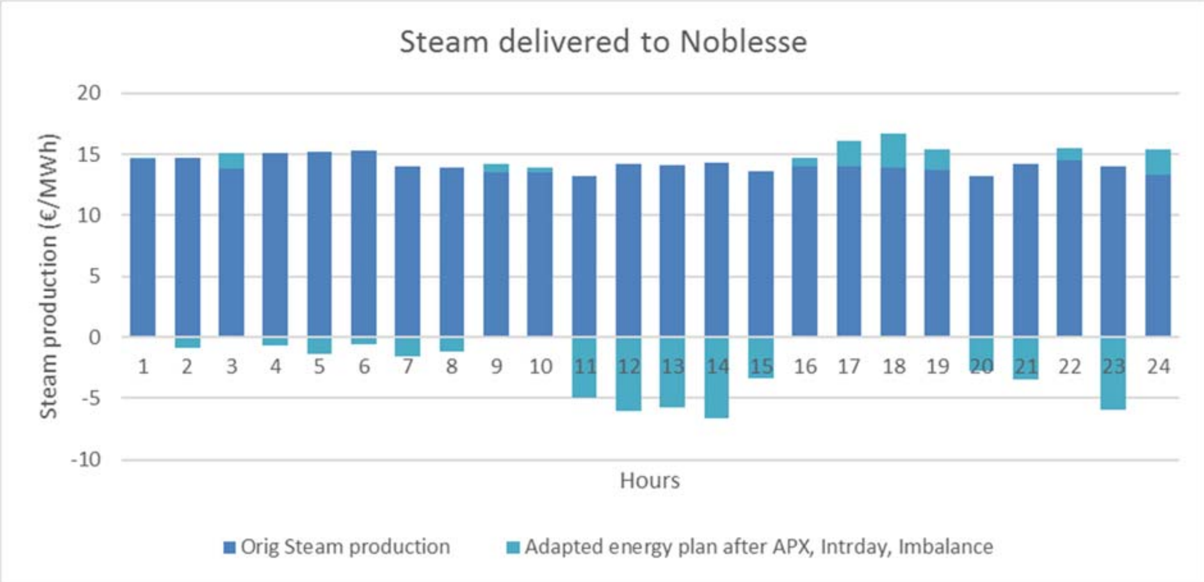

Figure 29 Steam delivered to Noblesse- optimized for day-ahead, Intraday and Imbalance

On this day, imbalance prices are profitable and much imbalance trade is taking place. By comparing Figure 26 and Figure 29, we can see that the energy plan which is optimized only for the APX day-ahead is changed as a result of imbalance trading. Because the quantity shift always takes the APX optimized steam production as a reference, the total quantity shift can be maximum twice as high (6MW in this case) when the imbalance optimization moves in the opposite direction of the APX optimization (low points (decreased electricity production in favor of steam) in the APX optimized energy plan are increased to high points (increased electricity production at the expense of steam production)). Due to a high number of upregulating (high prices) there is less steam delivered than the planned amount. The shortcomings in steam are made up for the next day.

Figure 30 shows the new and old revenue as a result of APX day-ahead optimization and additional trade on the Intraday and Imbalance market. On this particular day, the additional revenue from electricity sales is 66 percent. On average, the additional revenue gained from the flexible operation stems from 20 percent of Imbalance trade and from 80 percent of APX day-ahead optimization.

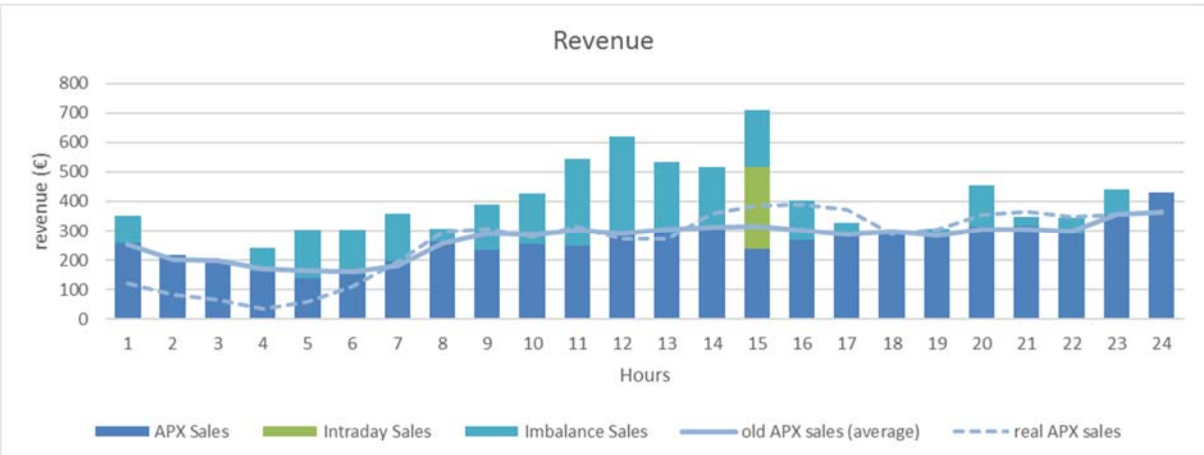

Figure 30 Breakdown of revenue on day-ahead, Intraday and Imbalance.

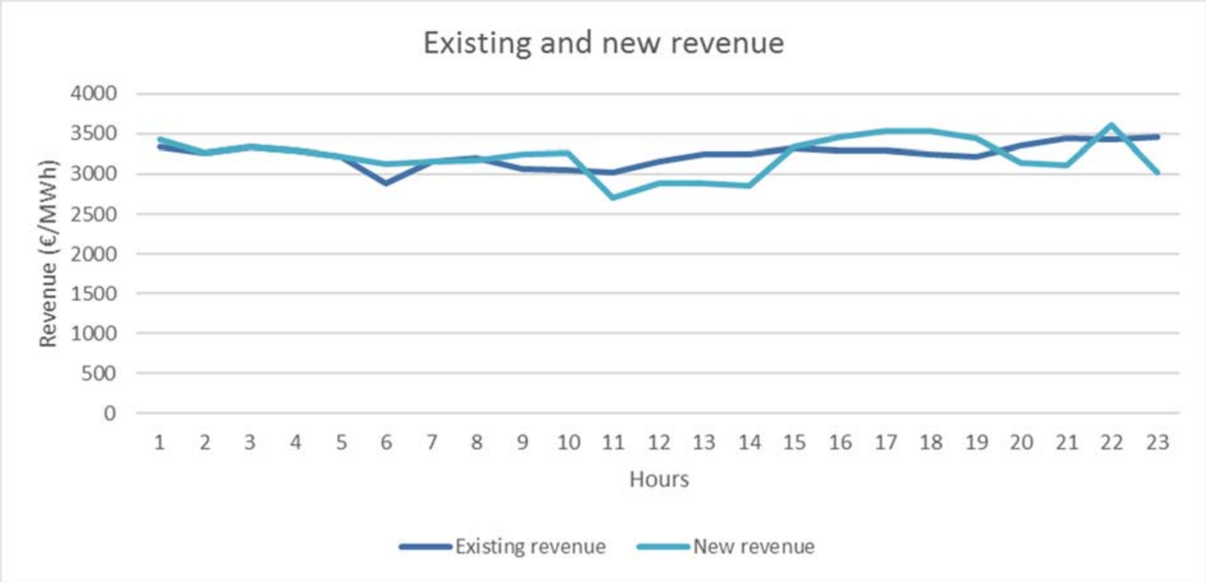

Figure 31 Existing and new revenue

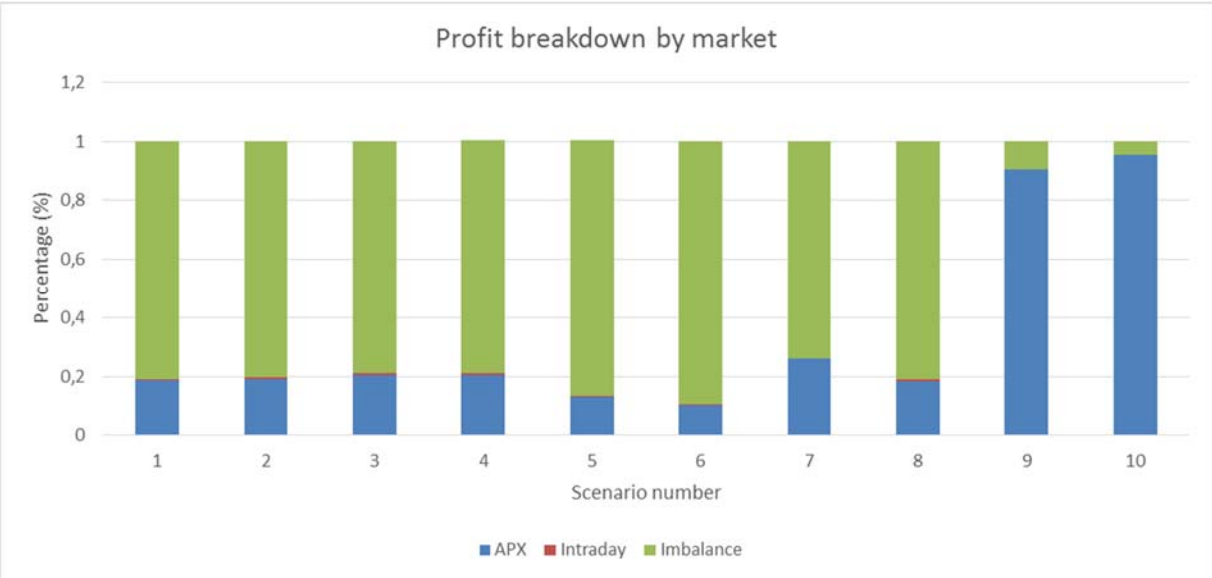

Figure 32 Profit breakdown per market (of yearly revenue)

<u>For the district heating scenario</u>
The model applies the same methodology as for the Noblesse scenario. Here, the flexibility is not achieved by adapting the consumption but by a seasonal or daily storage.

In the daily storage scenario, the heat extraction is equal to the heat demand. We use the storage to store any surplus of heat when we need to minimize the electricity production (up to the maximum heat extraction of 60 MW). The model optimizes for the day-ahead, intraday and imbalance markets as described above. The threshold for the Intraday and Imbalance markets is in this scenario not determined by the marginal costs of shifting the production but by the cost of the storage, which is equal to the heat loss.

In the seasonal storage scenario, we utilize the maximum heat extraction of 60 MW continuously. Any quantity of extracted heat that is higher than the demand is stored in a seasonal buffer. During summer, the surplus of extracted heat is stored and used for the deficit during winter. In this scenario it is possible to extract more heat, but there is only little flexibility because the full heat storage capacity is used to level out the variation in heat demand between summer and winter time. This becomes obvious from the results: absolute profits are higher (more heat is sold), but the additional profit caused by the flexibility is low.

7.4. Sensitivity analysis

Running a number of simulations by changing one variable at a time gives the basis for the sensitivity analysis. The results from the sensitivity analysis are included in the different scenarios as presented in Table 6. The variable that are changed in the scenarios are:

1. Production shift (3 MW, 5 MW and 9 MW)
2. Time shift (2 hours, 4 hours, 6 hours and 12 hours)
3. Treshold (lower APX threshold of 33,5 €/MWh and higher Intraday/Imbalance threshold of 150 €/MWh)

From the results we can conclude the following:

- Increasing the time shift only causes small revenue increases. A time shift of 12 hours even decreases the revenue. A longer time shift means that the energy plan is optimized on the APX for more consecutive hours, which limit the opportunities to optimize further for Intraday and Imbalance markets.
- Increasing the production shift causes revenue increase in a rather linear causation: when there is more heat available for flexibility, the electricity that can be utilized flexibly increases along.
- Changes in threshold obviously effects total revenue as the number of trades executed increase or decrease. Increasing the threshold for the Intraday and Imbalance market from 87,5 €/MWh (base case) to 150 €/MWh causes a revenue decrease from 9,09 percent to 8,14 percent. Decreasing the threshold for the APX day-ahead market from 37,5 €/MWh to 33,5 €/MWh causes a revenue increase from 9,09 percent to 9,28 percent.

8. Business case

In the previous chapter we have outlined how the techno-economic model calculates potential revenue. In this section, we will review the business case (viability) of the flexible business model for ETP Wijster. Thereby, we also take into account the costs of implementing the business model (OPEX and CAPEX) and other financial variables such as lifetime and depreciation. We will review the business case for the following scenarios:

8.1. APX day-ahead only option

Table 8 describes the variables that characterise APX day-ahead only option. In this option Attero, and their customers trade only on the APX market. That is Noblesse offers Attero their flexibility, and based on the available flexibility Attero trades on the APX day-ahead market.

Table 8 Parameters and variables for the APX only option

Capex	*Quantity*	*Units*
Cost of software (e-web)	100000	€
Hardware costs	0	€
APX	0	€
Total capex	100000	€
Opex	*Quantity*	*Units*
Marginal cost of shifting consumption	8590	€
Personel	14123	€
Maintenance costs 5% of Capex	5000	€
APX transaction costs (0,08/MWh)	0	€
Transactional costs for per for internal aggregator MW(0,75/MWh)	0	€
External aggregator profit sharing (50% of imbalance)	€ 0	€
Total Opex	27713	€
Revenue	*Quantity*	*Units*
Increased revenue APX sales	17155	€
Revenue from imbalance trading	0	€
Revenue from intraday trading	0	€
Total revenue	17155	€
Other variables	*Quantity*	*Units*
AMT of revenue shared with external aggregator/pv	0,00%	
Number rampus and downs	1718	
Marginalcost for ramping up and down	5	€/Cycle
Timeshift	2	Hrs
Qty shift	3	MWh
Cost of capital	10,00%	%
Depriciation	10,00%	%
Tax	25,00%	%

Here we will describe the important variables that characterise this option. In this option, we assume that Noblesse is able to shift their consumption by $3MWh_t$ and up to 2 Hrs (forward or backward). Additionally, we have assumed a 10 percent required rate of return, 10 percent linear depreciation, and a lifetime of 10 years. Furthermore, the CAPEX is estimated at €100.000 euros. This investment cost mainly covers the additional investments Noblesse has to make to generate additional flexibility for e.g. storage.

Since Attero operates on the APX day ahead market and Attero knows well in advance the flexibility offered by Noblesse we assume that Attero has enough time to adapt its production schedule. Therefore, we assume that no change to Attero's infrastructure is necessary. Further, we have arbitrarily assumed that Noblesse has a marginal cost of 5€/cycle for ramping up and down their consumption. This could include additional costs associated with flexibility such as, additional cost of storing raw materials, exhaustion of technical elements, administrative burden etc. A cycle is defined as the act of deviating from the planned consumption schedule and then getting back to the normal consumption schedule. Another unique characteristic of this scenario is that we assume that no additional personnel is needed to handle trade on APX. We have assumed that Attero has the necessary capabilities in house to trade on APX day-ahead. Nevertheless, we account for the additional administrative burden this will create. Furthermore, we have excluded the investment costs necessary for APX trading because we assume that Attero already has the necessary infrastructure and access to the APX trading platform.

Additional variables for this scenario can be found in Table 8.

We further explore worst case, most likely case, and best case scenarios for the APX day-ahead only option. In order to do that we vary three variables that could most likely change, and that has large impact on the viability of the business model.

Table 9 Worst case, most likely case, and best case scenario for APX day-ahead only option

Variables	***Worst case***	***Most likely case***	***Best case***	***Units***
NPV	-179079	-167679	20418	€
Marginal cost of shifting consumption	5	5	0	€/Cycle
Investment in hardware/infra	100000	100000	0	€
Revenue	15249	17155	19061	€/Year

Best case: The best case scenario has a positive NPV of approximately € 20.000 over a period of 10 years. Since Attero and its partner firms operate on the APX day-ahead market we assume that Noblesse and Attero have enough time to plan their production and consumption accordingly. Though unlikely, we assume that there are no additional investments necessary in the infrastructure because even in their current situation they have the capability to adapt production and consumption. Additionally, we assume that Noblesse has no marginal cost of shifting consumption. Here we assume that Noblesse is able to adapt their production process in such a way that avoids marginal cost of shifting consumption. Noblesse can do this by adopting just in time delivery techniques and adapting their production process as per the APX price patterns that are stable and highly predictable. Additionally, we assume that Noblesse is able to offer flexibility in such a way that allows Attero to maximise their revenue on the APX market, and that Attero is able to capitalise on all the arbitrage opportunities in a way that maximises their revenue.

Most likely case: From Table 9 we see that the most likely case has a negative NPV of approximately € 168 thousand. Here we have assumed that Noblesse will have to invest €100.000 to create the flexibility that allows them to shift in energy consumption. We assume that the investments will mainly be necessary for storage and insulation for maintaining the batch under production at a certain temperature. Additionally, we also assume that no investments are necessary on Attero's end. Furthermore, we also assume that Noblesse will have marginal cost of shifting consumption of € 5 per cycle. We chose this number arbitrarily because of lack of information. Furthermore, we assume that Attero is not able to capitalise on all the profitable trades and their revenue drops by 10 percent compared to the best-case scenario.

Worst case scenario: In the worst case scenario the NPV is a negative € 179 thousand. In this scenario all the variables remain unchanged except that the revenue drops by another 10 percent.

8.2. APX Day-ahead, Intraday, and Imbalance option

In this option, Attero and its partner firms trade on APX day-ahead market, intraday market, and the imbalance market respectively.

Table 10 displays all the variables that characterise this option. The idea here is to capitalise on the arbitrage opportunities that exist on the APX day-ahead market first, intraday market second, and imbalance market third. These trades are limited by the available capacity to ramp up or down and the relative positions in the other markets. For example, if Attero has already sold the maximum available electricity on the day-ahead market (including what Noblesse offered), it cannot sell additional electricity on the intraday market or the imbalance market even if the revenue on these markets is higher. However, if Attero has maximized the capacity to ramp up on the day-ahead and the intraday market it can then make use of the arbitrage opportunities for ramping down on the imbalance market.

Here we will describe the important variables that characterise this option. In this option, we assume that Noblesse is able to shift their consumption by $3MWh_t$ and up to 2 Hrs. Additionally, we have assumed a 10 percent required rate of return, 10 percent linear depreciation, and a life time of 10 years. Furthermore, the CAPEX is estimated at € 600000. This investment costs covers acquisition and setup of an intelligent system that can control the flow of energy based on the trades executed on the markets, and the flexibility offered by Noblesse to Attero. This investment is necessary to automate the process of offering flexibility, and to control the flow of energy. This is necessary because the reaction time necessary to react on the imbalance market is very short sometimes it can be as short as 4 seconds. Therefore, Attero and Noblesse should both be able to adapt their production and consumption process at 4 seconds notice. We have not included the cost for APX trading platform because we assume Attero already has access to the platform.

Furthermore, the number of trades on the markets drastically increases because the number of ramp-ups and ramp-downs increase. Here we have again arbitrarily assumed a marginal cost of shifting production/consumption of €5/Cycle. However, this cost may increase or decrease depending on the product, quantity shift, time shift, and the industrial process.

Due to the drastic increase in managing the complexity of trading on three markets and the coordination necessary between the partner firms and Attero we assume that there is a trained person working on this full time. Hence, the personnel cost increases. Furthermore, the revenue in this option also increases due to additional revenue from the intraday and imbalance market. However, there are additional costs to trading on the imbalance market, such as transaction costs that is paid to the external aggregator and the profit sharing with the external aggregator.

Table 10 Parameters and variables of the APX, Intraday, and Imbalance option

Capex	*Quantity*	*Units*
Cost of software	150000	€
Hardware costs	500000	€
APX	0	€
Total capex	650000	€
Opex	*Quantity*	*Units*
Marginal cost of shifting consumption	25640	€
Personel	50000	€
Operation and Maintenance costs of inrastructure 22% of Capex	143000	€
APX transaction costs (0,08/MWh)	0	€
Transactional costs for per for aggregator MW(0,75/MWh)	0	€
External aggregator profit sharing (50% of imbalance)	69.994	€
Total Opex	288634	€
Revenue	*Quantity*	*Units*
Increased revenue from APX sales	17155	€
Revenue from intraday trading	1962	€
Revenue from imbalance trading	111991	€
Total revenue	161012	€
Other variables	*Quantity*	*Units*
AMT of revenue shared with external aggregator/pv	50,00%	
Number rampus and downs	3205	
Marginalcost for ramping up and down	5	€/MWhe
Threshold price for apx	37,5	€
Threshold price for imbalance/intraday	87,9	€
Timeshift	2	Hrs
Qty shift	3	MWh
Cost of capital	10,00%	
Depriciation	10,00%	
Tax	25,00%	

Table 11 Worst case, most likely, and best case scenario for APX, Intraday, and Imbalance option

Variables	***Worst case***	***Most likely case***	***Best case***	***Units***
NPV	-1.388.315	-1.275.508	-953.130	€
Marginal cost of shifting consumption	8	5	5	€/Cycle
Investment in hardware / infra	650.000	650.000	600.000	€
Increased revenue from APX sales	14843	16699	18554	€
Revenue from intraday trading	1931	1931	1931	€
Revenue from imbalance trading	96437	110214	137767	€/Year
Revenue sharing agreement with aggregator	50%	50%	25%	%

Best case: From Table 11 the best case scenario has a negative NPV of approximately €0.95 million. In this scenario, we have arbitrarily assumed a marginal cost of shifting consumption of €5/cycle. As previously explained this accounts for the additional cost for creating flexibility. The revenue from imbalance and intraday trading increases. Here we assume that Attero is able to take advantage of all the profitable arbitrage opportunities that exist on all three markets. Furthermore, we assume that Attero pays 25 per cent of the revenue from the trades that exceed the threshold price.

Most likely case: This scenario has a negative NPV of approximately €1.27 million. Here we observe that the capex has increased to € 650.000. This accounts for deviations in the investment costs. Additionally, we assume that Attero is unable to take advantage of all the most profitable trades hence their revenues for the APX day-ahead market drop by 10 percent and the revenue for the imbalance trading drops by 20 percent. Furthermore, we assume that Attero has to pay 50 percent of the revenue from the trades exceeding the threshold price.

Worst case scenario: In this scenario the NPV further drops to approximately negative € 1.4 million. Here we assume that the investment cost stays the same as the most likely case. However, the marginal cost of shifting consumption increases to €8 per cycle due to unforeseen changes that might be needed at Noblesse or at Attero. Furthermore, we assume that the revenues from the APX day-ahead drop by 20 percent and the revenues from Imbalance trading drop by 30 percent when compared to the best-case scenario. Furthermore, we assume that Attero has to pay 50 percent of the revenue from the trades exceeding the threshold price.

8.3.Sensitivity of the business models

From the above analysis it is clear that with the available amount of flexibility it is hard to achieve a financially viable business model. However, viability can be achieved by increasing the flexibility offered (in the above case 7MWh thermal). Additionally, the business case also improves if the volatility on commodity markets improves. All of the options and scenarios presented above are highly sensitive to the CAPEX and the OPEX. In particular, the business model is highly sensitive to the investment costs in the hardware, marginal cost of shifting consumption, and the personnel cost. The required rate of return also has a negative impact on the NPV. Hence, Attero and the partner firms should try to minimise these expenses. Additionally, in case of scenarios that have a positive NPV the tax rate negatively affects the NPV. In the day-ahead, intraday, and the imbalance option, the revenue sharing with the external aggregator negatively influences the NPV. From Table 5 it can be concluded that the time shift does not have a significant impact on the revenue. The revenue marginally increases as the time shift increases up to six hours and there after it reduces. This can be attributed to the fact that Attero and its partner firms optimise their production and consumption to the APX day-ahead market as a result they are not able to take advantage of the arbitrage opportunities that exist on the intraday and the imbalance market. However, the increase in the quantity significantly increases the revenue. In addition, the process carried out by Noblesse is time sensitive because the quality of their raw material drastically reduces if the delay is more than 2 hours. Therefore, we set out to answer the question what is the minimum quantity needed to breakeven for the most likely scenario for both the APX day-ahead only option and the day-ahead, intraday, and the imbalance option.

For the most likely scenario for the APX day-ahead only option the total revenue will have to be approximately € 45300. Consequently, the flexibility in terms of quantity will have to be increased to 7 MWh thermal or about 2.25 MWh electric. It is important to note that the above recommendation is very specific to Noblesse as a partner firm and the assumed commodity prices, and the time shift. If we were not constrained by time shift, the revenue for the APX day-ahead only option could be increased by increasing the time shift. For the most likely scenario for the day-ahead, intraday, and imbalance option the total revenue will have to be approximately €365000 annually to break even over a period of 10 years. Consequently, the flexibility in terms of quantity will have to be increased to 7MWh thermal.

Additionally, all of the revenues are based on the day-ahead prices of 2015 and imbalance price of 2015. It is important to note that the prices on the day-ahead market in 2015 were very low. Furthermore, the volatility in the market in terms of euros is decreasing this also has a negative impact on the revenues earned. This can be countered by increasing flexibility in terms of quantity. However, experts forecast that the volatility will increase as renewable sources increase. Moreover, we have used the average monthly prices to simulate the trades. Therefore, the results could also slightly vary if the daily prices are used. The number of trades executed on the market also effects the revenue that in turn influences viability of the business model. In our simulations the only two factors that affected the number of trades the threshold price and the time constraint. The trades are executed only when the prices exceeds the threshold price, and the demand for heat cannot be shifted for more than 2 hours in either direction i.e., forward or backward.

9. Conclusions and recommendations

To deal with the rapidly changing energy landscape energy companies will require different business models. To be able to utilize the potential of trading flexibility, energy producers need business models that can harness and exploit flexibility in a viable manner. In order to help the companies at ETP Wijster with the abovementioned challenge we have developed and validated a business model that exploits multiple commodities and the flexibility of all the partner firms in a business ecosystem setting.

The study has shown that there are different sources of flexibility, and that flexibility can be traded on different commodity markets. We have shown the characteristics of the different markets (forward, day-ahead, intraday and imbalance) and have calculated the feasibility of trading flexible power on each of those markets. For each market and for each partner firm at the ETP we have come up with a strategy to trade heat and power in a flexible way. We have made a distinction of different sources of flexibility: 1) the ability to shift the demand pattern (postponing or advancing production by a certain amount of hours), 2) the ability to increase or decrease the demand and 3) the ability to use a heat buffer as a source of flexibility.

In order to validate the model we have used historical data of the day ahead, intraday, and imbalance market and we have simulated a set of trading strategies. For the day-ahead market we have optimized the energy plan based on historic daily patterns of electricity prices. For the intraday and day-ahead market prices are monitored in real-time and trades are executed when the prices are higher than the set threshold price. Additionally, we have also validated the technological architecture through expert interviews and by presenting the technological architecture to domain experts. The technical architecture was found to be feasible. The information systems architecture was found to be viable because similar variants of such systems already exist, for example the products of AgroEnergy (AgroEnergy, 2016). The physical systems architecture was also found to be feasible, but we have also identified a few bottlenecks including the fact that the change in electricity output should be large enough to be measurable, which will only occur at relatively large changes in heat consumption.

Our results show that it is possible to achieve a positive business case by trading only 3MWth thermal (approximately 0,9MWh electric) on the day ahead market. However, for a robust business case we need more flexibility. With about 7MWth thermal flexibility Attero and its partner will be able to break even in 10 years. Similarly for a robust business case for the day-ahead, intraday, and the imbalance option a minimum of 7MWth is needed. Therefore to summarize the quantity of flexibility offered by Attero and its partners should be higher and or the volatility of the electricity market should increase.

Due to the lack of data we have insufficiently validated the viability of the business model on the intraday market. However, the intraday market is – like the day-ahead – an easily accessible market. Through expert interviews we have learned that the intraday market, which is now fairly volatile, is expected to expand with the increase of renewable sources in the power system. It is not unthinkable that the intraday market will become at least as interesting as the imbalance market. Attero and other power producers could anticipate on that development by already starting to be active on this market. However, access to the imbalance market is not so straightforward. Market parties can only trade on the imbalance market through a PRP. Some PRP's have already developed services to make the imbalance market accessible to market parties, such as greenhouses.

To quantify the potential profit and the financial feasibility many assumptions are made concerning the variables used in the techno-economical model. Sensitivity analysis has shown that the feasibility is sensitive to volume (quantity shift), volatility on commodity markets, investment costs in the hardware, marginal cost of shifting consumption and the personnel cost. In the current situation there is only one heat consumer at the ETP for which we have assumed a flexibility of 3 MW. With this quantity there can just be a viable business case built with day-ahead optimization. With larger volumes, i.e. more connected firms, there is sufficient potential for a viable business case. This makes the business model also interesting for other industrial parks with a cogeneration power plant.

The study has also focused on the capabilities that need to be developed to implement the business model. Capabilities are categorized in technological capabilities, trading capabilities and process capabilities. First of all, Attero and the participating firms need to understand the technical possibilities and limitations of their facility regarding flexible operation. Also regarding access to the markets, capabilities need to be built. To be able to trade on the imbalance market for instance, the power producer needs to adapt technically to be able to follow the control signal from the PRP. Access to market through service products requires relations with the PRP, aggregator and service providers. The existence of an internal and external trading platform is key to the business model and operating it requires advanced knowledge of energy management. The communication between the different stakeholders that are connected through the trading platform takes place with ICT which needs to be implemented in the operating systems.

To trade flexibly on the day-ahead market capacities in energy management are required and only low investment costs are needed to implement the business model. By starting to operate in a flexible way only with the day-ahead market, Attero can explore and built the capabilities needed to operate a complex business model as is described in full detail in this report.

References

ACM. (2012). *Authority for Consumers and Markets National Report on energy regulation in 2012.* [pdf] Available at: <http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/NATIONAL_REPORTS/National%20Reporting%202013/NR_En/C13_NR_Netherlands-EN.pdf

ACM. (2016). *Warmtetarieven.* [online] Available at: <https://www.acm.nl/nl/onderwerpen/energie/warmte/warmtetarieven/> [Accessed 22 March 2016]

AgroEnergy. (2016). *Pilot met FlexLive: direct zakendoen met TenneT* [online] Available at: https://www.agro-energy.nl/Producten/FlexPower/FlexLive.aspx. [Accessed 21 April 2016]

Al-Debei, M. M., & Avison, D. (2010). Developing a unified framework of the business model concept. [Article]. *European Journal of Information Systems, 19*(3), 359-376. doi: 10.057/ejis.2010.21

APX Group. (2016). *Day-Ahead Auction.* [online] Available at: <https://www.apxgroup.com/trading-clearing/day-ahead-auction/> [Accessed 11 Jan 2016]

Blijswijk, Van, M., 2011. *Congestion management in the Dutch power sector: a quantitative evaluation of policy options.* [pdf] Available at: <http://repository.tudelft.nl/assets/uuid:b212b14c-ded2-4117-9164-5f8548d7ad20/Master_Thesis_Martti_van_Blijswijk_v1.03_public.pdf> [Accessed 11 Jan 2016]

Boots, M. (2011). The Dutch Electricity Value Chain. Arnhem, the Netherlands: KEMA Nederland B.V.

Breukers, A., Hietbrink, O., & Ruijs, M. (2008). The power of Dutch greenhouse vegetable horiticulture. *LEI Wageningen UR*.

Chesbrough, H., Vanhaverbeke, W., & West, J. (2006). *Open Innovation: Researching a New Paradigm*: Oxford University Press.

D'Souza, A., van Beest, N. R. T. P., Huitema, G. B., Wortmann, J. C., & Velthuijsen, H. (2015). A Review and Evaluation of Business Model Ontologies: A Viability Perspective. In J. Cordeiro, S. Hammoudi, L. Maciaszek, O. Camp & J. Filipe (Eds.), Enterprise Information Systems (Vol. 227, pp. 453-471): Springer International Publishing.

D'Souza, A., Wortmann, J. C., Huitema, G. B., & Velthuijsen, H. (2015). A business model design framework for viability; a business ecosystem approach. Journal of Business Models, 3(2).

Frunt, J. (2011). *Analysis of balancing requirements in future sustainable and reliable power systems.* Ph. D. Eindhoven University of Technology. Available at: <https://pure.tue.nl/ws/files/3014724/711271.pdf> [Accessed 28 Jan 2016]

Gordijn, J., Osterwalder, A., & Pigneur, Y. (2005). *Comparing two Business Model Ontologies for Designing e-Business Models and Value Constellations*. Paper presented at the 18th Bled eConference eIntegration in Action, Bled, Slovenia.

Jensen, A. B. (2014). Do we need one business model definition? *Journal of Business Models, 1*(1), 61-84.

Kraussl, Z. (2011). *OPerationalized ALignment: Assessing feasibility of value constellations exploiting innovative services.* PhD, Vrije Universiteit, Amsterdam.

Lamproupolos, I. et al. (2012). *Analysis of the market-based service provision for operating reserves in the Netherlands.* [pdf] Available at: http://www.e-price-project.eu/website/files/EEM%5C'12%20-%20I.%20Lampropoulos%20et%20al.%20[31-03-2012].pdf> [Accessed 12 Jan 2016]

Magretta, J. (2002). Why Business Models Matter. [Article]. *Harvard Business Review, 80*(5), 86-92.

NEDU. (2014). Detailprocesmodellen Mutatie- & meetprocessen Grootverbruik. Amersfoort: NEDU.

Oei, P. ; Vries, C. de. (2007). *Stoom op maat, haalbaarheid van elektriciteitslevering aan eind-gebruikers.* [pdf] Available at: <http://www.innovatienetwerk.org/sitemanager/download attachment.php?id=39To8vZ3BqhXWwJaZEaOQn> [Accessed 14 Jan 2016]

Osterwalder, A., & Pigneur, Y. (2002). *An e-business model ontology for modeling e-business.* Paper presented at the 15th Bled Electronic Commerce Conference.

Sawin, J. L. (2015). RENEWABLES 2015 GLOBAL STATUS REPORT. In L. Mastny (Ed.), *Renewables Global Status Report*. Paris, France: Renewable Energy Policy Network for the 21st Century.

Sewalt, M.P.G., Van Baar, G.M. and De Jong, C., (2003). *Prijsvorming in de vrije elektriciteitsmarkt.* [pdf] Available at: <http://www.managementexecutive.nl/downloaden/2844/Prijsvorming -in-de-vrije-elektriciteitsmarkt-de-invloed-van-negatieve-commodityprijzen-op-optiepremies>

TenneT. (2004). *Transparantie voor onbalanssytematiek.* [pdf] Available at: <https://www.acm.nl/nl/download/bijlage/?id=8350> [Accessed 11 Jan 2016]

TenneT. (2010a). *T-prognoses, nut en noodzaak.* [pdf] Available at: <http://www.tennet.eu/nl/fileadmin/downloads/Customers/Congestiemanagement/Brochure_T-prognoses_tcm41-19760.PDF> [Accessed 11 Jan 2016]

Tennet. (2010b). Preparation of E-programmes & T-forecast Using Excel converters: TenneT.

TenneT. (2011). *Notitie: Productinformatie regelvermogen.* [pdf Available at: <http://www.tennet.eu/nl/fileadmin/downloads/About_Tennet/Publications/Other_Publications/plugin-SOC_11-139_Productinformatie_regelvermogen_tcm41-13678.PDF> [Accessed 11 Jan 2016]

TenneT. (2012). *Simulatiehandleiding congestiemanagement.* [pdf] Available at: <http://emlab.tudelft.nl/congestion/emlab-congestion-brochure.pdf>

TenneT. (2013a). *Notitie: Productinformatie noodvermogen.* [pdf] Available at: <http://www.tennet.eu/nl/nl/over-tennet/nieuws-pers-publicaties/publicaties/technische-publicaties/productinformatie-noodvermogen.html> [Accessed 11 Jan 2016]

TenneT. (2013b). Product information emergency power, memorandum to suppliers of emergency power SOC 13-056 [pdf] Available at: <http://www.tennet.eu/nl/fileadmin/downloads/About_Tennet/ENGELS-SO-SOC_13-056_Productinformatie_noodvermogen.pdf> [Accessed 11 Jan 2016]

TenneT. (2014a). Process for the procurement of balancing reserves and balancing energy.

Tennet. (2014b). What is programme responsibility and how can you become a Programme-Responsible Party (PRP)? Retrieved from http://www.tennet.eu/ website: http://www.tennet.eu/nl/fileadmin/downloads/Customers/introduction_to_program_responsibility.pdf

TenneT. (2015). *Congestion management.* [online] Available at: <http://www.tennet.eu/nl/customers/congestion-management.html> [Accessed 11 Jan 2016]

Timmers, P. (1998). Business models for electronic markets. *Electronic Markets, 8*(2), 3-8.

Van der Veen, R. (2012*). Diffusion of combined heat and power in Dutch greenhouses: a case study (E. S. a. Services, Trans.).* Delft: Delft University of Technology.

Van der Velden, N., & Smit, P. (2014). Energiemonitor van de Nederlandse glastuinbouw 2013: LEI, Wageningen UR.

Vlap, H., Holstein, J., Van der Steen, A. and Grond, L. (2015). Demonstratieproject

Power-to-Gas in Rozenburg. [pdf] Available at: < file:///C:/Users/BOKH/Downloads/DNV%20G L%20- %20Rapport%20Demonstratieproject%20Power-to-Gas%20in%20Rozenburg.pdf>

Velden, N., & Smit, P. (2014). Energiemonitor van de Nederlandse glastuinbouw 2013. *LEI-rapport/LEI Wageningen UR (014-025)*.

Wetzels, W., van Dril, A., & Daniëls, B. W. (2007). *Kenschets van de Nederlandse glastuinbouw: ECN*.

Zott, C., & Amit, R. (2010). Business Model Design: An Activity System Perspective. [Article]. *Long Range Planning, 43*(2/3), 216-226. doi: 10.1016/j.lrp.2009.07.004

Zott, C., Amit, R., & Massa, L. (2011). The Business Model: Recent Developments and Future Research. [Article]. *Journal of Management, 37*(4), 1019-1042. doi: 10.1177/0149206311406265

Appendix A: Manual APX Price Matcher (techno-economic model)

The APX Price Matcher (or APM) is a model which is designed to simulate the optimum financial performance of the Attero energy plant. The goal of this model is to demonstrate the potential financial benefits of optimizing electricity production in relation to the APX, intraday and imbalance markets. In addition, we explore the possibility of selling steam to a "high-end" consumer (e.g. Noblesse) and / or a "low-end" consumer (e.g. a district heating system for 10,000+ households). We do this by simulating each day of the year in one-hour time blocks and generating an energy plan which focuses on meeting the energy demand of thermal energy clients while simultaneously optimizing the profits obtained from electricity sales on the various electricity markets.

Disclaimer: This model is only meant to provide a guideline for *potential* revenue. Many unknown factors, such as the costs associated with ramping a steam turbine up or down, are not incorporated in this model.

Main Display - Calculations

The main display (named "Calculations") is where a user can change variables to explore their effect on the financial performance of the Attero energy plant. By changing these variables, we can simulate the effect of implementing a new energy plan. The primary variables are described below:

1. **Start Day:** The day of the year the simulation will start with (e.g. February 1st in day 32).

2. **End Day:** The day of the year the simulation will end with. *Note that the model takes 2-3 minutes per day to perform the calculations, so it is not advisable to run more than a month at a time unless you are prepared to leave your computer running for several hours.*

3. **Turbine Variability:** The following factors limit the degree to which we are allowed to vary the steam turbine's performance within this simulation.
    a. **Max production shift (MW_t):** This is the maximum amount thermal power which we can deviate away from the steam turbine in order to increase or decrease electricity production.
    b. **Max Time Shift (hours):** In this model, we assume that we will always try to deliver our thermal energy clients their required amount of thermal energy. However, we also assume that we can shift this demand by a given amount of hours, represented by this variable.

For example, if we have a Max Production Shift of ±3 MW_t and a Max Time Shift of 2 hours, then our model will assume that within each one-hour time block, we can shift thermal power by ±3 MW_t *on the condition that we increase / decrease thermal energy delivery to account for any shortfall / surplus thermal energy within the desired time shift.* So, if we decrease thermal energy delivery by 3 MW_t at 1:00, then by 3:00 (i.e. within 2 hours), we must increase thermal energy delivery by 3 MW_t to account for the steam we did not deliver earlier.

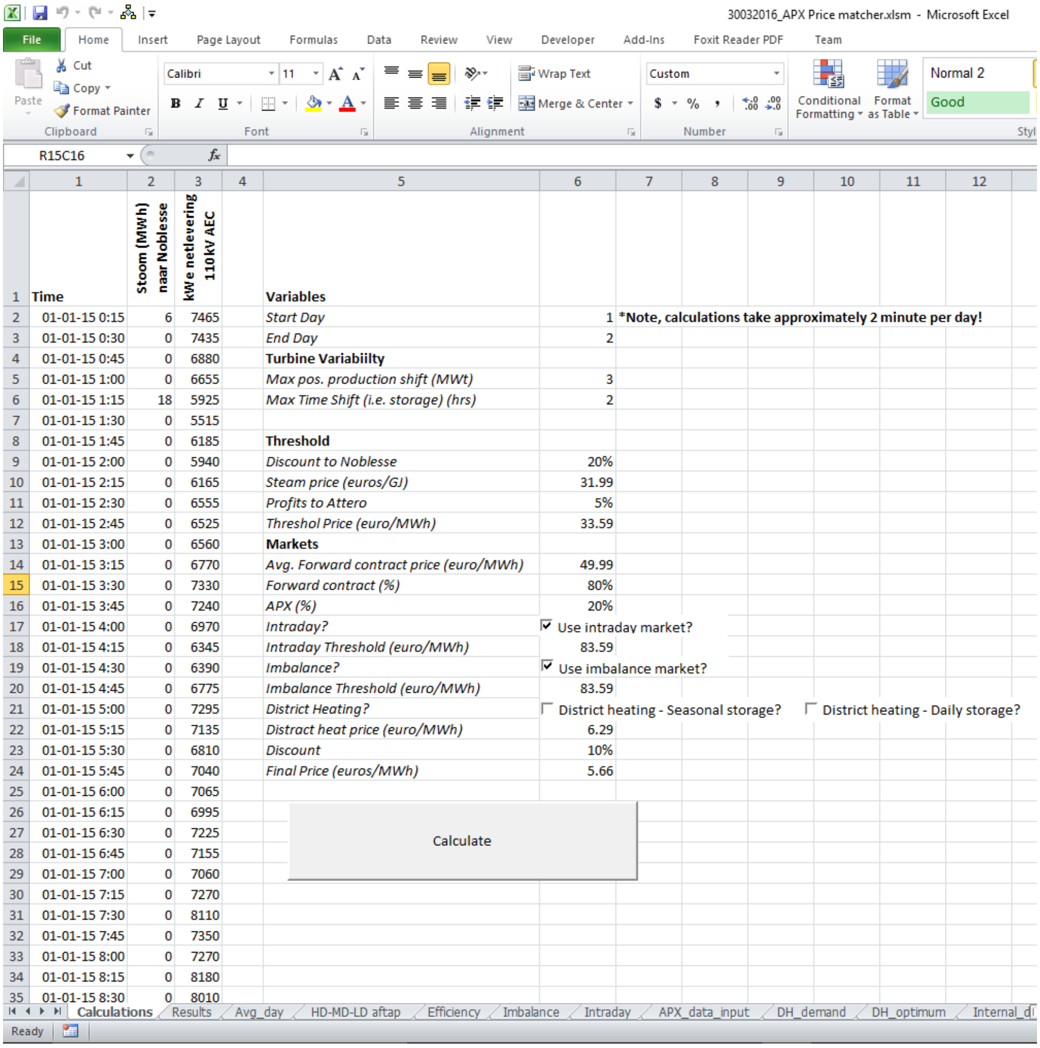

Figure 33 - Main Display of the APM model

4. **Threshold:** In order to make decisions regarding which market to sell electricity on or whether we should focus solely on thermal energy production, we must establish various thresholds. These thresholds indicate the price-point at which it will become beneficial to produce more electricity rather than steam.
    a. **Discount to Noblesse:** The discount on thermal energy, assuming the price is set relative to the APX price.
    b. **Steam Price (€/GJ):** The price at which Attero sells steam to their "high-end" customers. This price is set equivalent to the average APX price with the discount to Noblesse (i.e. 3 MWh_t will have roughly the same price as 1 kWh_e, minus 25%). The steam price can be set to any value.
    c. **Profits to Attero (%):** The amount of additional value gained for selling steam.
    d. **Threshold Price (€/MWh):** The price at which it becomes beneficial to produce additional electricity in favour of producing steam. This can be set to any value desired.

5. **Markets:** There are many electricity markets and all behave differently. Here we define many variables which will determine how the simulation will interact with each market.
    a. **Average forward contract price (€/MWh):** The price of electricity when using forward contracts. This is calculated at €10 above the average APX price, but it can be set to any value.
    b. **Forward contract percentage (%):** The percentage of base electricity produced which will be sold to forward contracts (the remainder will be sold on the APX market).
    c. **APX percentage (%):** The percentage of base electricity produced which will be sold on the APX market. *The Forward contract percentage and APX percentage should add up to 100%!*
    d. **Intraday?** Check this box to indicate that we will participate in the intraday market.
    e. **Intraday Threshold (€/MWh):** The price at which it becomes beneficial to produce additional electricity for the intraday market in favour of producing steam. This value should include the costs to both Attero and all "high-end" thermal energy customers for an unplanned shift in thermal energy production.
    f. **Imbalance?** Check this box to indicate that we will participate in the imbalance market.
    g. **Imbalance Threshold (€/MWh):** The price at which it becomes beneficial to produce additional electricity for the imbalance market in favour of producing steam. This value should include the costs to both Attero and all "high-end" thermal energy customers for an unplanned shift in thermal energy production.
    h. District Heating? Check *one* of these boxes to indicate that we will sell steam to a "low-end" district heating system.
        i. Seasonal Storage: With this strategy, we assume that we have a virtually unlimited heat buffer and we will sell as much thermal energy as possible (assumed to be a constant 60 MW_t of low-quality heat). We supply heat to 40,000 housing equivalents; we assume a storage efficiency of 80% and a thermal transportation efficiency of 90%.
        ii. Daily Storage: With this strategy, we assume that we have a 24 hour thermal storage buffer. In this way, we have maximum flexibility regarding steam production and we are only limited in that we must meet thermal demand within each 24 hour cycle. We supply heat to 16,000 housing equivalents; we assume a storage efficiency of 90% and a thermal transportation efficiency of 90%.
    i. District heat price (€/MWh): The district heating price is equal the maximum heat tariff according to the heat law, which is 22,64 €/GJ (ACM, 2016)
    j. Discount: The discount offered on the district heat price.
    k. Final price (€ / MWh): The final price received for thermal energy after taking the discount into account. This can be set to any value.

How the model works

The model is designed to optimize the financial aspects of energy production within a 24 hour period. Each day is analyzed independently, with some possible carry-over effects from the previous day. In order, the model will go through the following steps, described in detail below, for each hour of the day.

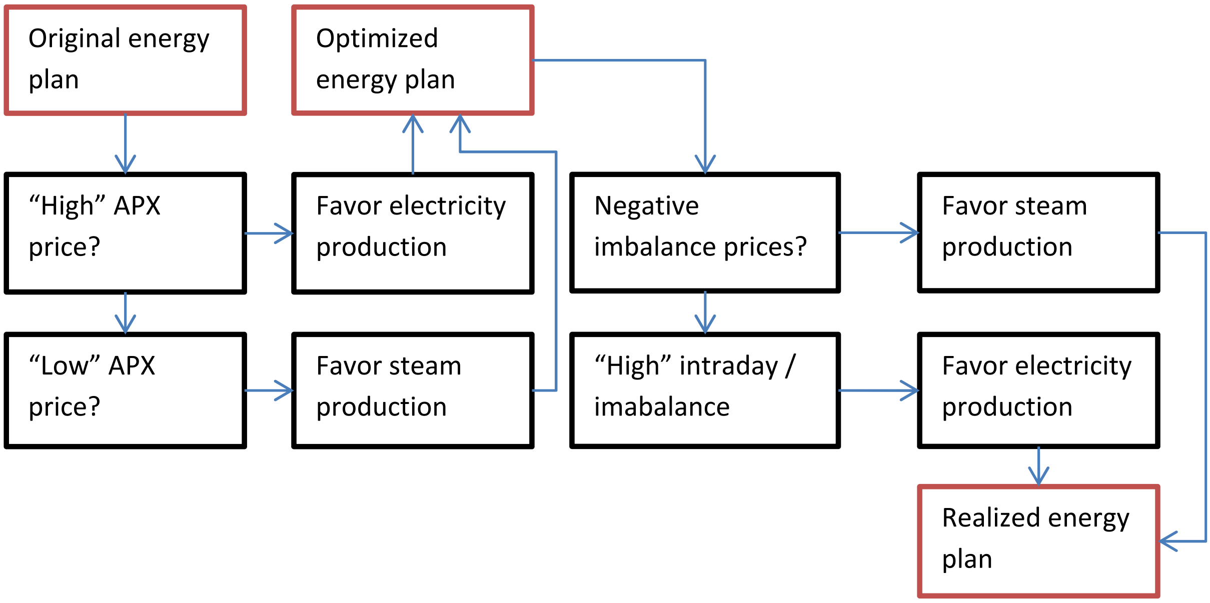

Figure 34 - Model overview

1. **Read in data**

The first action of the model is to read in all the important data. This includes all the user-defined variables, described above, as well as the relevant, customizable data sets, described below:

a. **Calculations:** On the main page, we use a data set provided by Attero to determine our "current situation" as a reference scenario. We use the measurements regarding electricity production and steam demand for a high-end thermal energy client to determine "current" profits. Measurements are taken on a 15 minute time scale, but we sum them to a 1 hour time scale.
b. **APX Prices:** We take the monthly average APX prices for the previous year in order to predict the optimal hours for electricity production for a given month.
c. **Intraday Prices:** Simply, we take the hourly intraday prices for the previous year. Assuming that future prices will be similar, we treat these numbers as if they were current. Hence, we use the 2015 pricing data to simulate a "real-time" intraday market. Prices are on a 1 hour time scale.
d. **Imbalance Prices:** Similar to the intraday prices, but using data for the imbalance market and using a 15 minute time scale.
e. **Heat Demand Pattern:** We use a simulated daily heat demand pattern for a given number of houses (depending on the scenario chosen).

2. **Original energy plan (i.e. reference scenario)**

Based on the Attero data on the Calculations page, we calculate our "current" (i.e. reference) situation. Simply, we multiply electricity production with the forward contract price and APX price (in a ratio determined by the user) to determine electricity sales. We then add this to the steam production multiplied by the steam price. This provides us with the revenue stream from our '**original energy plan**', which is used as a reference for all other scenarios.

3. Optimized energy plan (i.e. APX market optimization)

Since this energy plan is based on APX prices, we plan electricity / steam production for each hour of the day. We allow steam production (and thereby electricity production) to shift up or down by the amount defined by the *Max Production Shift* variable.

We use a 'brute force' approach to determine the optimum energy production plan for the following day, assuming that we will follow the average monthly APX price pattern. The limitation with this optimization is that the total quantity of thermal energy delivered must not change within a given time block (i.e. the time period defined by the *Max Time Shift* variable).

In addition, we assume that we will not affect the energy plan while the APX price is lower than the defined *Threshold* price. The exception to this rule is that we allow the energy plan to reduce electricity production (i.e. increase steam production) immediately prior to or after an increase in electricity production due to high APX prices. In this way, we plan to produce as much electricity as possible while electricity prices are high, and produce steam to compensate for this while electricity prices are low.

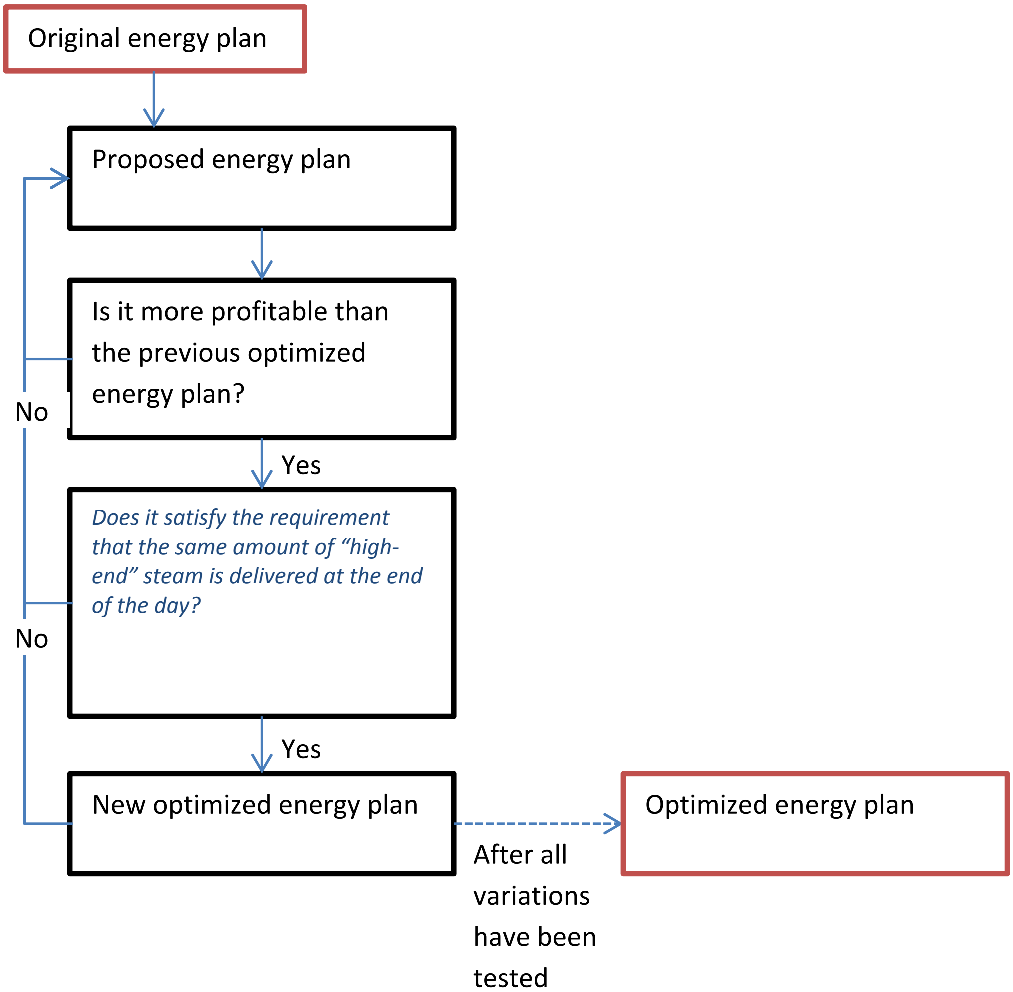

Figure 35 APX optimization procedure

Following this, we check the demand of our heat clients – if this is zero, we maximize our electricity production at all times. Additionally, we ensure that our total daily steam demand is met, and we account for any steam shortcomings from the previous day in the earliest hours of the morning (when market prices tend to be at their lowest).

Based on this optimization process, we have now constructed an '**optimized energy plan**'.

4. Utilize the intraday market

Once we have our energy plan set, we move through the day in "real time". When we see an hourly intraday price which is higher than our intraday threshold, we focus on electricity production (still limiting our shift in production to the variable defined earlier). Our threshold assumes that we exceed the cost of steam production *in addition to* the cost for the heat client to shift their production plan. In the business plan, Attero would compensate their heat clients for a shift in steam production to make up for any losses in their own production.

Any shortcomings in total daily steam production as a result of these shifts are made up in the earliest hours of the following day. In this way, thermal energy demand is always met, though not necessarily at the 'correct' point in time.

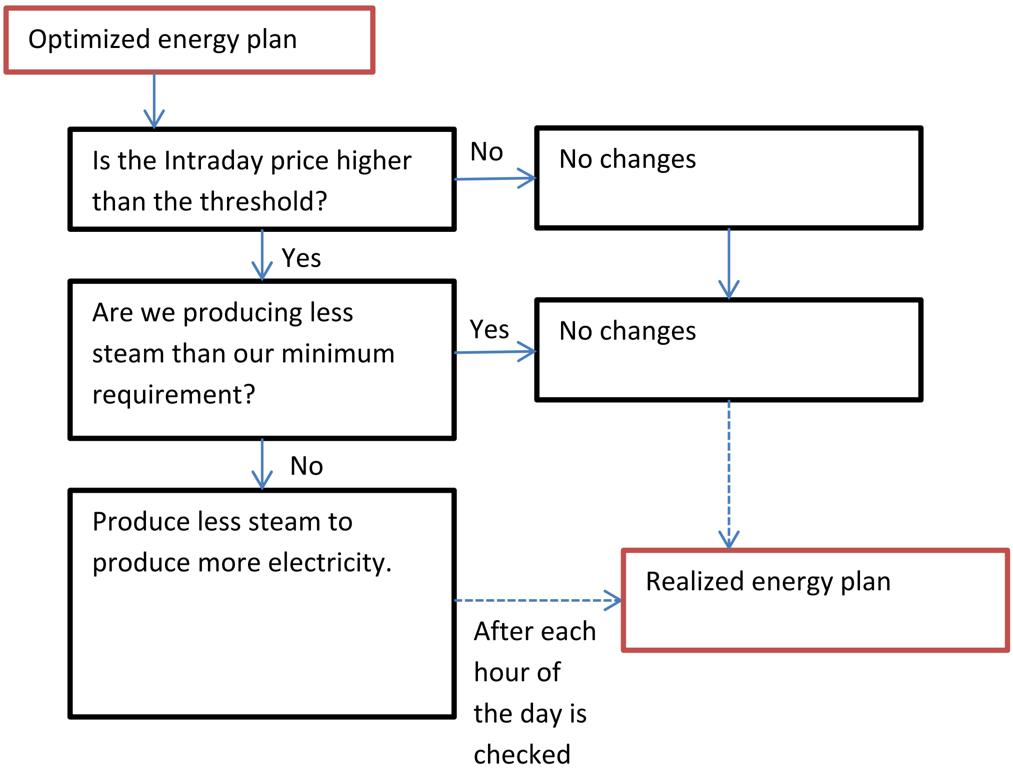

Figure 36 - Intraday market algorithm

5. Utilize the Imbalance market

The Imbalance market is analyzed on 15 minute time scale. The method is identical to the Intraday market described above with the following exceptions:

i. First, if the imbalance market is in an inconsistent state (state = 2), then no trading is done on the market since prices are volatile and the market state is unpredictable.
ii. Second, if the state of the imbalance market is in downregulation (i.e. state = -1), then we will reduce electricity production and favor steam production (still limiting our shift in production to the variable defined earlier). In this way, we still profit from our "unsold" electricity and gain an additional payment for downregulating.
iii. Finally, if the state of the imbalance market is in upregulation (i.e. state = +1), then we will increase electricity production and decrease steam production (still limiting our shift in production to the variable defined earlier). In this way, we still profit from our "unsold" electricity and gain an additional payment for downregulating.

Any shortcomings in total daily steam production as a result of these shifts are made up in the earliest hours of the following day. In this way, thermal energy demand is always met, though not necessarily at the 'correct' point in time. Surpluses in steam production generate additional heat sales revenue.

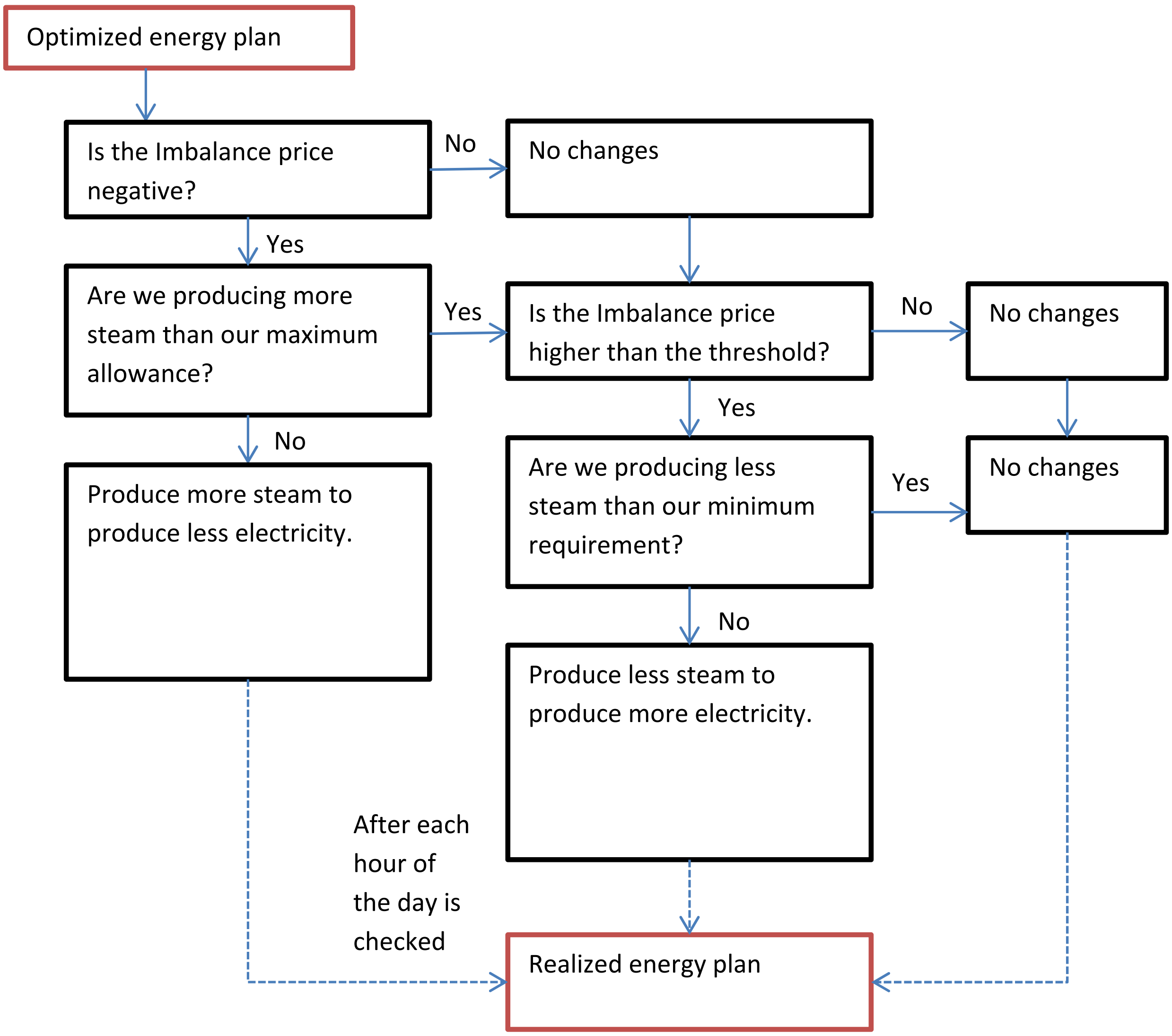

Figure 37 - Imbalance market algorithm

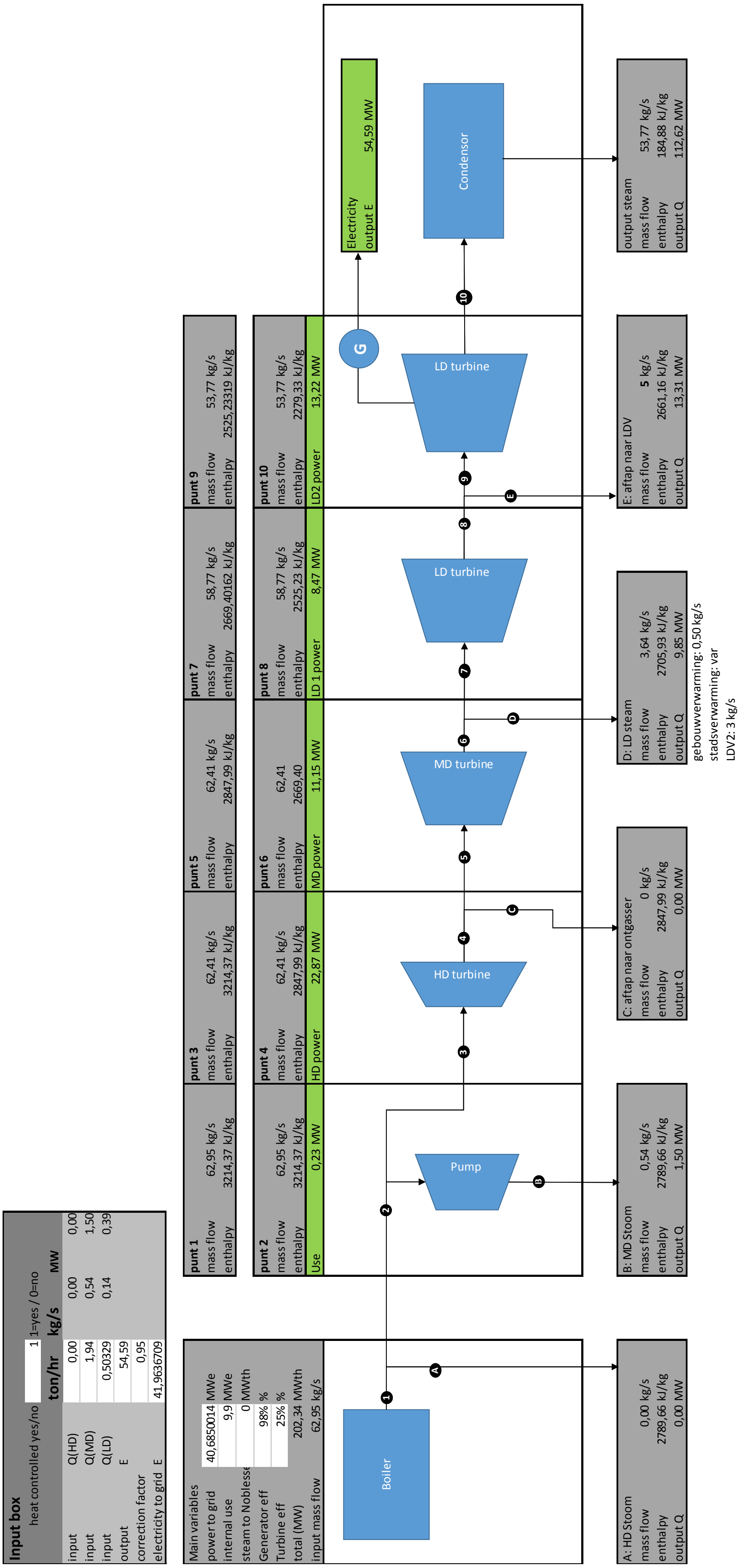

Figure 38 Interface of the Steam Turbine Model

Based on the above shifts to accommodate the different energy markets, we calculate our final revenue stream based on our '**realized energy plan**'.

Steam Turbine Model

The Steam Turbine Model is a thermodynamic model which demonstrates the effect of changing steam production on electricity output. This model is used to determine changes in electricity production resulting from changes to our daily energy plan. As we do not know the real steam production from the boiler for each hour in 2015, the model uses the electricity production data and the steam production data for each hour in 2015 to calculate the steam production. Then the Steam Turbine Model takes this calculated steam production as an input to determine how much of the steam is used for electricity production and how much for steam production in the new situation.

Low-end thermal energy demand patterns (i.e. District heating)

Part of this study also includes the possibility for Attero to provide thermal energy to "low-end" clients, such as in a district heating system. Our "low-end" thermal energy demand patterns are based on measured values for houses from another study.

For this scenario, we introduce two possible strategies:

i. **Seasonal storage:** We utilize the maximum heat extraction of 60 MW to provide heat for as many houses as possible (40,000). We assume a seasonal buffer that can moderate the winter peaks by using the heat from the summer that is stored in the buffer. In this way, we produce heat year round.

ii. **Daily storage:** We produce enough heat (60 MW_t) to meet the demand of a given number of houses (16,000) on the coldest day of the year. We also assume that we have a 24 hour storage buffer. In this way, we can utilize the flexibility of the storage to optimize our electricity production on all but the coldest days of the year. We optimize our "low-end" heat production following the same principles described above. Flexibility allows us to preload our thermal storage while APX, intraday and imbalance prices are low, and utilize stored energy to maximize electricity production when APX, intraday or imbalance prices are high. We also favor steam production when imbalance prices are negative. We have a minimum threshold electricity price which must be reached before we switch from steam to electricity production; this price is set at 8 times the price of heat (simply, 8 MW_t delivered is roughly equivalent to 1MW_e delivered). Finally, to ensure we always meet our heat demand, we set a 'storage target' (i.e. the amount of thermal energy which should be placed in storage) based on the expected daily thermal energy demand, as shown below. Reaching this storage target overrides all other factors which might alter our energy plan.

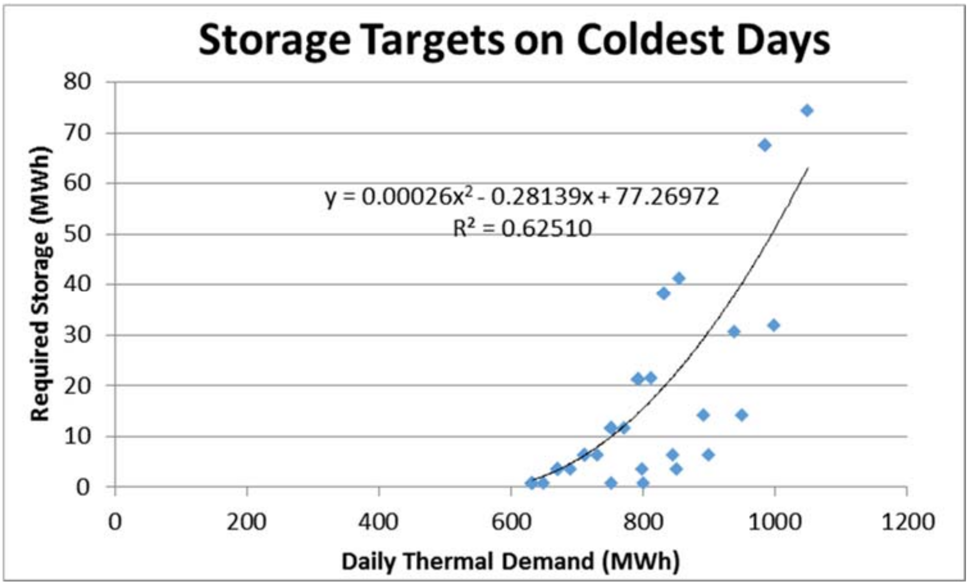

Figure 39 - Calculating storage targets on cold days

Results

Once the model has finished running, we can view the results on the "Results" page. These numbers and figures can give insight into the proposed energy plan. From left to right, the columns on the "Results" page provide the following information:

a. **Steam sold (MWh):** The quantity of steam sold to both "low-end" and "high-end" customers.
b. **Electricity produced (MWh):** The quantity of electricity produced in the 'realized energy plan'.
c. **Old revenue:** The amount of revenue generated in the 'original energy plan'.
d. **New revenue:** The amount of revenue generated in the 'realized energy plan'.
e. **Profit:** The relative difference between the New and Old revenue streams on a daily basis (presented as both an absolute difference and a percentage difference). A positive value indicates that the New revenue stream is higher than the Old revenue stream and vice versa.
f. **Profit Breakdown:** A breakdown of the different components which make up the New revenue stream. These include:
   i. **Forward contract sales**
   ii. **APX sales**
   iii. **Intraday sales**
   iv. **Imbalance sales**
   v. **"High-end" steam sales**
   vi. **"Low-end" steam sales**
   vii. **Internal steam sales**
g. **Ramp ups:** The number of times during the year in which electricity production is ramped up to produce additional electricity for higher market prices. This value gives some insight into the flexibility required in order to achieve an optimum energy plan.

Average Day

In addition to the results listed above, we can also view the results for the average of the days simulated. Selecting the “Avg_day” page will show the average results for the range of days which were simulated.

Appendix B: Interface Hydrogen model

input box		
scenario	Hydrogen - electricity	
treshold APX	20	€/MWh
treshold Imbalance	0	€/MWh
Variables gas production		
sale price hydrogen	5	€/m3
sale price methane	0,6	€/m3
compression efficiency	0,000056	MWh/m3
Running hours APX (based on treshold)	218	h
Running hours IMB (based on treshold)	2307	15 min
hydrogen produced	253,33	m3/h
hydrogen produced	22,77	kg/h
methane produced	0,00	m3/h
yearly production	201336,67	m3/year
yearly revenu	1006683,33	€
CAPEX		
Investment electrolyzer	4000000,00	€
Investment compressor	760000,00	€
Investment methanation	0,00	€
Investment hydrogen storage	37183,67	€
Investment turbine/generator	0,00	€
Total (CAPEX)	4797183,67	€
OPEX		
fuel cost steam/electricity (total 1 year)	-44128,12	€
electricity cost for compression	170028,56	€
cost of CO2	0,00	€
maintenance electrolyzor	0,025	%
maintenance methanation	0,000	%
Total (OPEX)	225900,44	
Other variables		
discount rate	10%	%
depreciation period	10	years
tax	0,25	%

years	0	1	2	3	4	5	10
revenue		1006683	1006683	1006683	1006683	1006683	1006683
opex		225900	225900	225900	225900	225900	225900
net result		780783	780783	780783	780783	780783	780783
net cumulative result		780783	1561566	2342349	3123132	3903914	7807829
cash flow (EBITA)	-4797183,667	780783	780783	780783	780783	780783	780783
ROI(return on investment)		-84%	-67%	-51%	-35%	-19%	63%
depreciation		479718	479718	479718	479718	479718	479718
book value	-4797183,667	-4317465	-3837747	-3358029	-2878310	-2398592	
EADABT		301065	301065	301065	301065	301065	301065
EAT		225798	225798	225798	225798	225798	225798
EATBDA		705517	705517	705517	705517	705517	705517
NPV		-4.087.381	-3.442.106	-2.855.492	-2.322.207	-1.837.402	389
NPV	€ 389,19						